THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

VOL. XXIX · NO. 114 · APRIL 1961

CONTENTS

J. Quarterman: The Digestibility of Crude Fibre in the Tropics . 101
H. Epstein: The Development and Body Composition of Docked and Undocked Fat-tailed Awasi Lambs. With Plate 2 . . . 110
J. E. Peat and K. J. Brown: A Record of Cotton Breeding for the Lake Province of Tanganyika: Seasons 1939–40 to 1957–8 . . 119
E. Boswinkle: Residual Effects of Phosphorus Fertilizers in Kenya 136
D. N. Barua: The Significance of Seed-size in Cultivated Tea (*Camellia Sinensis L.*) 143
J. Smartt: Groundnut Varieties of Northern Rhodesia and their Classification 153
E. Cresswell, A. H. Kirton, and D. F. G. Orwin: Note on the Daily Grazing Distances of Six Romney Ewes, Three of which were Treated with L-Thyroxine. With Plate 3 159
E. Cresswell: Note on the effect of Shearing, and of Drenching with Simulated Rain, on the Oxygen Consumption and Respiratory Pattern of Sheep. With Plates 4, 5, 6 162
A. Troughton: Studies on the Roots of Leys and the Organic Matter and Structure of the Soil 165
Irena Krupko and R. L. Davidson: An Experimental Study of *Stoebe Vulgaris* in Relation to Grazing and Burning. With Plates 7, 8, 9 175
R. K. Djokoto and D. Stephens: Thirty Long-term Fertilizer Experiments under Continuous Cropping in Ghana. I . . . 181

OXFORD
AT THE CLARENDON PRESS: 1961

PRINTED IN GREAT BRITAIN BY VIVIAN RIDLER AT THE UNIVERSITY PRESS, OXFORD

EDITORIAL BOARD OF THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

Sir E. J. RUSSELL, Campsfield Wood, Woodstock, Oxfordshire (*Chairman*).
Dr. E. E. CHEESMAN, Agricultural Research Council, 15 Regent Street, London, S.W. 1.
Sir J. B. HUTCHINSON, School of Agriculture, Cambridge.
Sir G. W. NYE, Colonial Office, Sanctuary Buildings, Great Smith Street, London, S.W. 1.
Dr. G. WATTS PADWICK, Plant Protection Ltd., Fernhurst, near Haslemere, Surrey.
D. RHIND, Colonial Office, Sanctuary Buildings, Great Smith Street, London, S.W. 1.
Sir J. A. SCOTT WATSON, 4 Sheldon Avenue, London, N. 6.

(*The above constitute the Executive Committee*)

M. A. A. ANSARI, Pakistan Central Cotton Committee, New Queens Road, Karachi, 1.
Prof. R. G. BASKETT, National Institute for Research in Dairying, Shinfield, nr. Reading.
Prof. G. E. BLACKMAN, Dept. of Agriculture, Oxford.
Dr. M. F. CHANDRARATNA, Dept. of Agriculture, Peradeniya, Ceylon.
Sir G. F. CLAY, Malayan Rubber Fund, P.O. Box 2073, Kuala Lumpur, Malaya.
Dr. D. P. CUTHBERTSON, Rowett Research Institute, Aberdeen.
Dr. WILLIAM DAVIES, Grassland Research Institute, Hurley, nr. Maidenhead, Berks.
Dr. H. P. DONALD, Animal Breeding Research Organization, Edinburgh 9.
Dr. W. L. FIELDING, Gwebi Agricultural College, Salisbury, Federation of Rhodesia and Nyasaland.
Dr. C. H. GOULDEN, Central Experimental Farm, Ottawa, Canada.
Dr. W. M. HAMILTON, Dept. Scientific and Industrial Research, Wellington, C. 1, New Zealand.
Sir J. HAMMOND, School of Agriculture, Cambridge.
Dr. P. S. HUDSON, Commonwealth Bureau of Plant Breeding and Genetics, Cambridge.
G. V. JACKS, Commonwealth Bureau of Soils, Harpenden, Herts.
J. LAMB, West African Cocoa Research Institute, P.O. Box 8, Tafo, Ghana.
Dr. A. H. LEWIS, Jealott's Hill Research Station, Bracknell, Berks.
Dr. J. MELVILLE, Waite Agricultural Research Institute, Glen Osmond, S. Australia.
Dr. B. P. PAL, Indian Agricultural Research Institute, New Delhi.
Prof. S. J. du PLESSIS, Dept. of Agricultural Technical Services, Private Bag 116, Pretoria, Union of South Africa.
Dr. E. W. RUSSELL, East African Agricultural and Forestry Research Organization, P.O. Box 21, Kikuyu, Kenya.
Prof. P. T. T. THOMAS, Welsh Plant Breeding Station, Aberystwyth.
Dr. F. R. TUBBS, Horticultural Research Station, East Malling, Kent.
Prof. STEPHEN WATSON, Dept. of Agriculture, Edinburgh University.
Dr. F. YATES, Rothamsted Experimental Station, Harpenden, Herts.

Secretary and General Editor
H. J. PAGE, Max Gate, Hurst Green, E. Sussex.

NOTICE TO CONTRIBUTORS

Papers submitted for insertion and all communications other than subscriptions should be sent to H. J. Page, Max Gate, Hurst Green, E. Sussex, but authors residing overseas should, where possible, send their papers through the local member of the Editorial Board; they should also name agents in Britain to whom proofs, &c., may be referred.

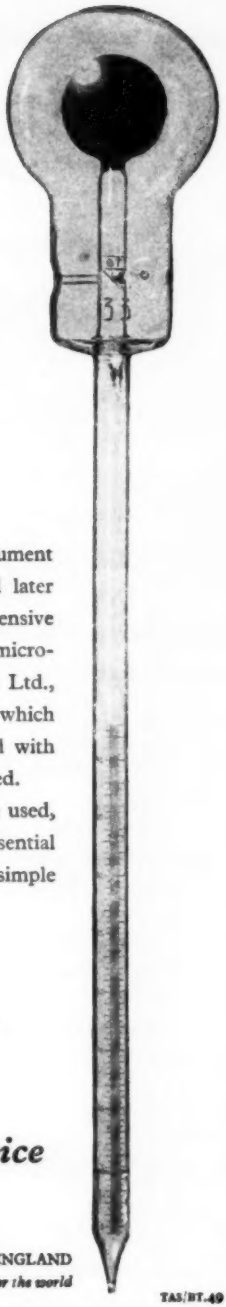
Authors are asked to submit their papers, finished in all details, in typescript with double-line spacing, and with ample margins. Illustrations should if possible be drawn, about twice the size of the finished block, on smooth, white Bristol board in Indian ink, with marginal lettering inserted in pencil. Their order and approximate position in the text should be marked. The length of papers, including tabular matter and illustrations, should not exceed the equivalent of 5,000 words. An allowance at the rate of ten shillings per sheet of sixteen pages is made for alterations in the proof (printer's errors excepted), and contributors will be responsible for any excess.

The address to which proofs are to be sent should be written on the paper and, when returning corrected proofs to the Editor, authors should state whether they desire to purchase additional offprints. Twenty-five offprints are allowed free of charge.

The Journal is normally published four times yearly by The Oxford University Press, Amen House, Warwick Square, London, E.C. 4, to whom subscriptions should be addressed.

SUBSCRIPTION FOR FOUR CONSECUTIVE NUMBERS 45*s.* POST FREE;
SINGLE NUMBERS 14*s.* net

The publishers are signatories to the Fair Copying Declaration in respect of this journal. Details of the Declaration may be obtained from the offices of the Royal Society upon application.



Gunn-Bellani radiation integrator

The thermal efficiency of the century-old Bellani instrument has been improved by Gunn, Kirk & Waterhouse, and later by Pereira, from 4% to over 75%. The instrument has extensive applications in meteorology, agriculture, irrigation, micro-climatology and biophysics. Baird & Tatlock (London) Ltd., offer it in two forms—without condenser (as illustrated), which is recommended for replicated field experiments; and with condenser where the highest available accuracy is required.

Their moderate price enables adequate numbers to be used, over a catchment area for example, thus providing an essential link between expensive recording thermopiles and the simple meteorological records taken at out-stations.

Write for Technical Leaflet No. T86, which describes the instrument and gives the results of extensive comparisons with other instruments

B T L *complete laboratory service*

BAIRD TATLOCK (LONDON) LTD., CHADWELL HEATH, ESSEX, ENGLAND
Branches in London, Manchester, Glasgow. Agents throughout U.K. and all over the world

TAS/BT.49

[1 *front*]

EDITORIAL BOARD OF THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

Sir E. J. RUSSELL, Campsfield Wood, Woodstock, Oxfordshire (*Chairman*).
Dr. E. E. CHEESMAN, Agricultural Research Council, 15 Regent Street, London, S.W. 1.
Sir J. B. HUTCHINSON, School of Agriculture, Cambridge.
Sir G. W. NYE, Colonial Office, Sanctuary Buildings, Great Smith Street, London, S.W. 1.
Dr. G. WATTS PADWICK, Plant Protection Ltd., Fernhurst, near Haslemere, Surrey.
D. RHIND, Colonial Office, Sanctuary Buildings, Great Smith Street, London, S.W. 1.
Sir J. A. SCOTT WATSON, 4 Sheldon Avenue, London, N. 6.
(*The above constitute the Executive Committee*)
M. A. A. ANSARI, Pakistan Central Cotton Committee, New Queens Road, Karachi, 1.
Prof. R. G. BASKETT, National Institute for Research in Dairying, Shinfield, nr. Reading.
Prof. G. E. BLACKMAN, Dept. of Agriculture, Oxford.
Dr. M. F. CHANDRARATNA, Dept. of Agriculture, Peradeniya, Ceylon.
Sir G. F. CLAY, Malayan Rubber Fund, P.O. Box 2073, Kuala Lumpur, Malaya.
Dr. D. P. CUTHBERTSON, Rowett Research Institute, Aberdeen.
Dr. WILLIAM DAVIES, Grassland Research Institute, Hurley, nr. Maidenhead, Berks.
Dr. H. P. DONALD, Animal Breeding Research Organization, Edinburgh 9.
Dr. W. L. FIELDING, Gwebi Agricultural College, Salisbury, Federation of Rhodesia and Nyasaland.
Dr. C. H. GOULDEN, Central Experimental Farm, Ottawa, Canada.
Dr. W. M. HAMILTON, Dept. Scientific and Industrial Research, Wellington, C. 1, New Zealand.
Sir J. HAMMOND, School of Agriculture, Cambridge.
Dr. P. S. HUDSON, Commonwealth Bureau of Plant Breeding and Genetics, Cambridge.
G. V. JACKS, Commonwealth Bureau of Soils, Harpenden, Herts.
J. LAMB, West African Cocoa Research Institute, P.O. Box 8, Tafo, Ghana.
Dr. A. H. LEWIS, Jealott's Hill Research Station, Bracknell, Berks.
Dr. J. MELVILLE, Waite Agricultural Research Institute, Glen Osmond, S. Australia.
Dr. B. P. PAL, Indian Agricultural Research Institute, New Delhi.
Prof. S. J. du PLESSIS, Dept. of Agricultural Technical Services, Private Bag 116, Pretoria, Union of South Africa.
Dr. E. W. RUSSELL, East African Agricultural and Forestry Research Organization, P.O. Box 21, Kikuyu, Kenya.
Prof. P. T. T. THOMAS, Welsh Plant Breeding Station, Aberystwyth.
Dr. F. R. TUBBS, Horticultural Research Station, East Malling, Kent.
Prof. STEPHEN WATSON, Dept. of Agriculture, Edinburgh University.
Dr. F. YATES, Rothamsted Experimental Station, Harpenden, Herts.

Secretary and General Editor
H. J. PAGE, Max Gate, Hurst Green, E. Sussex.

NOTICE TO CONTRIBUTORS

Papers submitted for insertion and all communications other than subscriptions should be sent to H. J. Page, Max Gate, Hurst Green, E. Sussex, but authors residing overseas should, where possible, send their papers through the local member of the Editorial Board; they should also name agents in Britain to whom proofs, &c., may be referred.

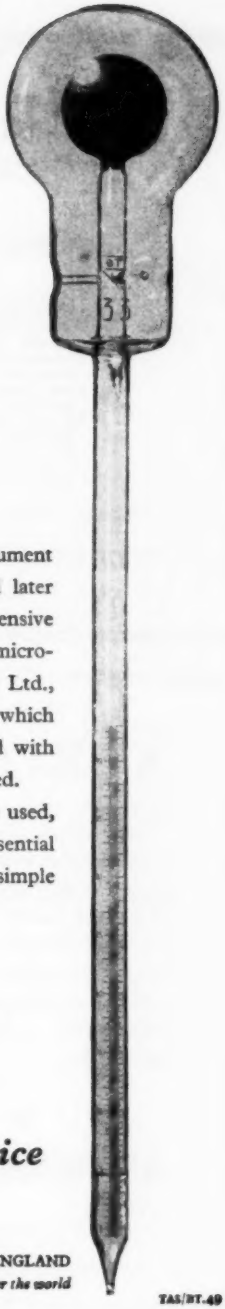
Authors are asked to submit their papers, finished in all details, in typescript with double-line spacing, and with ample margins. Illustrations should if possible be drawn, about twice the size of the finished block, on smooth, white Bristol board in Indian ink, with marginal lettering inserted in pencil. Their order and approximate position in the text should be marked. The length of papers, including tabular matter and illustrations, should not exceed the equivalent of 5,000 words. An allowance at the rate of ten shillings per sheet of sixteen pages is made for alterations in the proof (printer's errors excepted), and contributors will be responsible for any excess.

The address to which proofs are to be sent should be written on the paper and, when returning corrected proofs to the Editor, authors should state whether they desire to purchase additional offprints. Twenty-five offprints are allowed free of charge.

The Journal is normally published four times yearly by The Oxford University Press, Amen House, Warwick Square, London, E.C. 4, to whom subscriptions should be addressed.

SUBSCRIPTION FOR FOUR CONSECUTIVE NUMBERS 45*s.* POST FREE; SINGLE NUMBERS 14*s.* net

The publishers are signatories to the Fair Copying Declaration in respect of this journal. Details of the Declaration may be obtained from the offices of the Royal Society upon application.



Gunn-Bellani radiation integrator

The thermal efficiency of the century-old Bellani instrument has been improved by Gunn, Kirk & Waterhouse, and later by Pereira, from 4% to over 75%. The instrument has extensive applications in meteorology, agriculture, irrigation, micro-climatology and biophysics. Baird & Tatlock (London) Ltd., offer it in two forms—without condenser (as illustrated), which is recommended for replicated field experiments; and with condenser where the highest available accuracy is required.

Their moderate price enables adequate numbers to be used, over a catchment area for example, thus providing an essential link between expensive recording thermopiles and the simple meteorological records taken at out-stations.

Write for Technical Leaflet No. T86, which describes the instrument and gives the results of extensive comparisons with other instruments

BTL *complete laboratory service*

BAIRD TATLOCK (LONDON) LTD., CHADWELL HEATH, ESSEX, ENGLAND
Branches in London, Manchester, Glasgow. Agents throughout U.K. and all over the world

TAS/BT.49

[1 *front*]

THE JOURNAL OF
THE BRITISH GRASSLAND SOCIETY

A medium for the publication of the results of research and practical experience in the realm of Grassland Husbandry

Editor: A. G. G. HILL

CONTENTS OF VOLUME XVI. No. 1. MARCH 1961

INCLUDE

The effect on the soil of the components and management of a ley. By A. Troughton.

Farmers' reasons for not adopting controversial techniques in grassland farming. By D. Sheppard.

The effect of drill width on the seed productivity of leafy varieties of three grass species. By H. M. Roberts.

Some economic aspects of the application of phosphates to permanent pastures in Ireland. By M. Neenan, W. E. Murphy and A. Conway.

Studies of the growth of a Hyparrhenia-dominant grassland in Northern Rhodesia. II. Fertilizer Responses. III. The effect of fire. By N. R. Brockington.

The effect of nitrogenous fertilizer on an established white clover sward. By D. W. Cowling.

Published quarterly. Subscription, Vol. 1, 15 shillings, or $2; Vols. 2–12, 30 shillings, or $4. Annual Subscription, thereafter, 40 shillings or $5.60 per volume.

Articles for publication should be sent to: A. G. G. Hill, Editor, Journal of the British Grassland Society, c/o Commonwealth Bureau of Pastures and Field Crops, Hurley, Berks, England

Orders to: The Secretary, British Grassland Society, c/o Grassland Research Institute, Hurley, Berks, England.

AGRONOMY JOURNAL

This official organ of the American Society of Agronomy is now a bimonthly publication of up-to-date reports of general agronomic research. (It alternates with CROP SCIENCE, which carries reports of a more technical nature in crop breeding, genetics, and physiology.) Workers in the fields of forages and pastures, crop improvement, cultural practices, soil fertility, and allied areas of investigation will find articles of lasting interest in AGRONOMY JOURNAL. Publication is open to members of the American Society of Agronomy.

$12 per year in U.S. and Canada
$13 per year elsewhere

AMERICAN SOCIETY OF AGRONOMY

2702 Monroe Street
Madison 5, Wisconsin, U.S.A.

TROPICAL AGRICULTURE

The Journal of the
Imperial College of Tropical Agriculture
and
Faculty of Agriculture, University College of the West Indies

General Editor: G. B. MASEFIELD, M.A., A.I.C.T.A.
Department of Agriculture, University of Oxford

JANUARY 1961

Experiments on Cocoa Drying in the Cameroons — *G. A. R. Wood*
Comparison of Soil Covers during Cocoa Establishment on Clear-felled Land — *R. K. Cunningham and R. W. Smith*
Influence of Petroleum Oil on Photosynthesis of Banana Leaves — *J. M. Riedhart*
Premature Yellowing of Lacatan Bananas — *H. N. Hasselo*
Note on the Reversion of the Dwarf Banana 'Cocos' to 'Gros Michel' — *D. L. Richardson*
Productivity of Pasture in British Honduras—II. Pangola Pasture — *D. H. Romney*
Direct and Residual Effects of *Striga* Control Treatments on Sorghum Yields — *F. T. Last*
The Influence of Seed Quality on the Early Growth of Cashew — *A. K. Auckland*
The Chemical Defoliation and Desiccation of Tropical Woody Plants — *W. A. Brun, H. J. Cruzado and T. J. Muzik*
The Effect of Spacing on the Yield of Egg Plant (*Solanum melongena*) — *J. S. Campbell and G. E. Hodnett*

Annual Subscription 50*s.* (**$7.00**) *post free*
Single issues price 12*s.* 6*d. post free*

A Quarterly Publication from

BUTTERWORTHS

88 Kingsway, London WC2, in association with

THE UNIVERSITY COLLEGE OF THE WEST INDIES

THE JOURNAL OF
THE BRITISH GRASSLAND SOCIETY

A medium for the publication of the results of research and practical experience in the realm of Grassland Husbandry

Editor: A. G. G. HILL

CONTENTS OF VOLUME XVI. No. 1. MARCH 1961

INCLUDE

The effect on the soil of the components and management of a ley. By A. Troughton.

Farmers' reasons for not adopting controversial techniques in grassland farming. By D. Sheppard.

The effect of drill width on the seed productivity of leafy varieties of three grass species. By H. M. Roberts.

Some economic aspects of the application of phosphates to permanent pastures in Ireland. By M. Neenan, W. E. Murphy and A. Conway.

Studies of the growth of a Hyparrhenia-dominant grassland in Northern Rhodesia. II. Fertilizer Responses. III. The effect of fire. By N. R. Brockington.

The effect of nitrogenous fertilizer on an established white clover sward. By D. W. Cowling.

Published quarterly. Subscription, Vol. 1, 15 shillings, or $2; Vols. 2–12, 30 shillings, or $4. Annual Subscription, thereafter, 40 shillings or $5.60 per volume.

Articles for publication should be sent to: A. G. G. Hill, Editor, Journal of the British Grassland Society, c/o Commonwealth Bureau of Pastures and Field Crops, Hurley, Berks, England

Orders to: The Secretary, British Grassland Society, c/o Grassland Research Institute, Hurley, Berks, England.

AGRONOMY JOURNAL

This official organ of the American Society of Agronomy is now a bimonthly publication of up-to-date reports of general agronomic research. (It alternates with CROP SCIENCE, which carries reports of a more technical nature in crop breeding, genetics, and physiology.) Workers in the fields of forages and pastures, crop improvement, cultural practices, soil fertility, and allied areas of investigation will find articles of lasting interest in AGRONOMY JOURNAL. Publication is open to members of the American Society of Agronomy.

$12 per year in U.S. and Canada
$13 per year elsewhere

AMERICAN SOCIETY OF AGRONOMY

2702 Monroe Street
Madison 5, Wisconsin, U.S.A.

TROPICAL AGRICULTURE

The Journal of the
Imperial College of Tropical Agriculture
and
Faculty of Agriculture, University College of the West Indies

General Editor: G. B. MASEFIELD, M.A., A.I.C.T.A.
Department of Agriculture, University of Oxford

JANUARY 1961

Experiments on Cocoa Drying in the Cameroons — *G. A. R. Wood*
Comparison of Soil Covers during Cocoa Establishment on Clear-felled Land — *R. K. Cunningham and R. W. Smith*
Influence of Petroleum Oil on Photosynthesis of Banana Leaves — *J. M. Riedhart*
Premature Yellowing of Lacatan Bananas — *H. N. Hasselo*
Note on the Reversion of the Dwarf Banana 'Cocos' to 'Gros Michel' — *D. L. Richardson*
Productivity of Pasture in British Honduras—II. Pangola Pasture — *D. H. Romney*
Direct and Residual Effects of *Striga* Control Treatments on Sorghum Yields — *F. T. Last*
The Influence of Seed Quality on the Early Growth of Cashew — *A. K. Auckland*
The Chemical Defoliation and Desiccation of Tropical Woody Plants — *W. A. Brun, H. J. Cruzado and T. J. Muzik*
The Effect of Spacing on the Yield of Egg Plant (*Solanum melongena*) — *J. S. Campbell and G. E. Hodnett*

Annual Subscription 50*s.* (\$7.00) *post free*
Single issues price 12*s.* 6*d. post free*

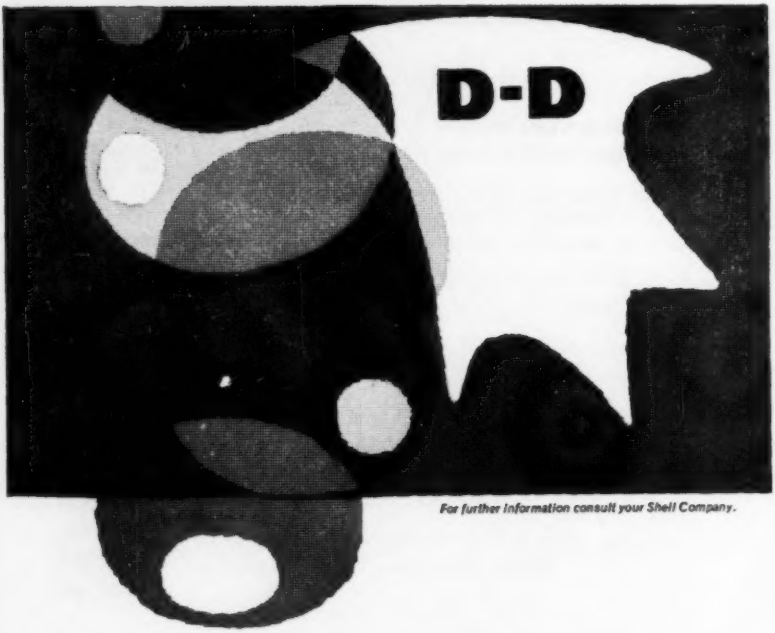
A Quarterly Publication from

BUTTERWORTHS

88 Kingsway, London WC2, in association with

THE UNIVERSITY COLLEGE OF THE WEST INDIES

Tomatoes protected against nematodes by D-D are healthy, abundant, profitable to the grower. When D-D is used before planting, nematodes perish, roots flourish, crops thrive. And profits with them. All over the world, the Shell soil fumigants **D-D** and **Nemagon,** and insecticides **aldrin, dieldrin, endrin** and **Phosdrin,** have made a world of difference to farmers. The difference between failure and success, between struggling survival and sound prosperity.



For further information consult your Shell Company.

In agriculture and industry Shell Chemicals SHELL

THE DIGESTIBILITY OF CRUDE FIBRE IN THE TROPICS

J. QUARTERMAN[1]

(*East African Agriculture and Forestry Research Organization*)

Summary

There is evidence in the literature that the digestibility of the crude fibre of fibrous feeds in the tropics is greater than that of fibrous feeds of the same crude-fibre level in temperate parts of the world. A small amount of data available suggests that the recovery of total lignin in crude fibre is much lower in fibrous feeds from tropical than from temperate parts of the world. It is shown how these two facts may be related.

Twenty feeds grown in Kenya, and fifty-two grown in the U.K., whose digestibility is known, have been analysed to determine the recovery of lignin in crude fibre. The feeds have similar crude-fibre contents and the digestibility of crude fibre in the two groups is the same but the Kenya feeds have a higher lignin content. Of the lignin of the Kenya feeds 17·4 per cent. was recovered in the crude-fibre fraction, and 29·7 per cent. of the lignin of the U.K. feeds.

The lignin in the faeces derived from these feeds shows similar differences in properties, but a smaller absolute amount of lignin is recovered in the faeces crude fibre than in a corresponding amount of the feed crude fibre.

THE proximate analysis of animal feedingstuffs is universally used as a guide to the nutritive value of the feed. The evaluation is based on relationships between the proximate analyses and the various criteria of nutritive value determined by Kellner, Armsby, and others in Europe and North America and by the use of relationships, such as that between crude fibre and the digestibility of organic matter, derived from the statistical analysis of the results of a large number of digestibility trials.

These relationships, although based on data mainly from temperate areas of the world, were assumed to be universally applicable, but workers in the tropics soon began to notice some differences. In 1921 Brunnich and Rawson [1] commented that the digestibility, by sheep, of some of the Queensland grasses, hays, and other fibrous feeds was greater than that to be expected by comparison with digestibility data from temperate parts of the world for feeds of the same crude-fibre content. Warth, beginning in 1926 [2, 3, 4], made a number of digestibility trials, mostly with indigenous Zebu cattle, and also noticed that the general level of digestibility of crude fibre of the local grasses at Bangalore was higher than the level which was quoted in the literature from North America. He attributed this difference to the supposedly superior ability of the Zebu cattle to digest the more fibrous fodder they are used to receiving. Lander and Dharmani in several papers [5] confirm this point and discuss the finding that the digestibility of the crude fibre often exceeded the digestibility of the nitrogen-free extract. They considered that this was a purely tropical phenomenon, but examples have since been found in temperate countries [6, 7, 8].

[1] Present address: The Rowett Research Institute, Bucksburn, Aberdeen.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

3988.114 H

These differences in crude-fibre digestibility between feeds in temperate and tropical parts of the world may be due to differences in the animals used, or to differences in the quality of the fibre of the feeds. This point was made by Duckworth [9], who showed that there was also a difference in the digestibility of organic matter between cattle in North America and in India, especially at low fibre levels.

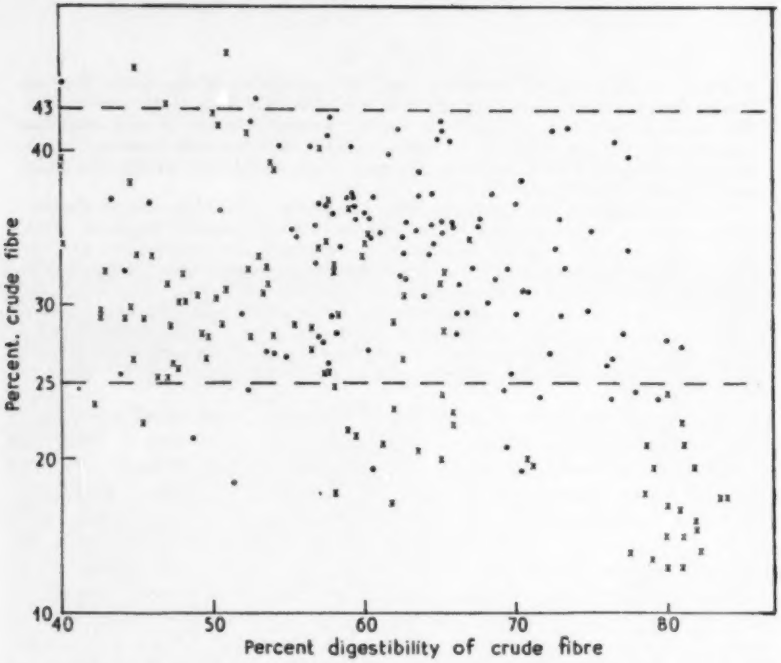


FIG. 1. The relationship between crude fibre and its digestibility in the tropics (•) and in temperate regions (x).

There is very little information about the comparative digestive powers of European cattle and tropical Zebu cattle or of animals of any species indigenous to the two areas. Digestibility trials with the two sorts of animals have been made on the same feeds by French [10]. Seven feeds had a crude-fibre content greater than 30 per cent. The digestibility of crude fibre in five of these is from 2 to 9·5 per cent. greater by the Zebu than by the European cattle. In the other two the digestibility is 0·2 and 2·4 per cent. lower by the Zebus. These data may be interpreted as showing the superior digestive powers of the Zebus with some feeds, but they may not be outside the normal range of error in digestibility trials.

Very little is known about any difference of digestive physiology between the two types of cattle. Hungate *et al.* [11] have found

a possible difference in rumen fermentation and Quarterman *et al.* [12] have found a difference in the large intestine.

The greater digestibility of crude fibre in the tropics noticed by Warth [2] and others and reviewed by French [13] is illustrated by comparing a selection of data from the literature from the two zones. Data from the temperate areas for grasses, hays, and straws were obtained from *Rations for Livestock* [14] and from the papers of Woodman *et al.* [15]. Data from tropical areas were obtained from Warth [2, 3, 4], Lander and Dharmani [5], Todd [16], Rogerson [17 and private communication], French [18], and P. McDonald in the Sudan (private communication). These data from temperate and tropical areas are shown on a scatter diagram, Fig. 1, in which the differences are clearly seen. The digestibility of crude fibre in feeds containing more than 25 per cent. of this constituent is greater in digestibility trials from the tropics than in trials from temperate areas. Between the limits of 25 and 43 per cent. crude fibre the mean digestibility coefficients for temperate and tropical areas are 50·8 and 62·5 per cent. respectively. Below a crude-fibre content of 25 per cent. most temperate feeds have a very high digestibility, and not many tropical feeds with such a low crude-fibre content have been examined. Many more data of this sort are available in the literature, but the basis of the division of the world into temperate and tropical climatic zones is an arbitrary one and no doubt it would be possible to find a gradation between the extremes if smaller climatic zones were considered.

In looking for an explanation of this difference in digestibility of crude fibre in feeds of the same crude-fibre content in the two climatic zones a difference was observed in the composition of the crude fibre itself. Norman [19] in England first analysed crude fibre for lignin, cellulose, and other constituents, and found a wide variation in the composition as far as lignin content, at least, was concerned. Much of the lignin is dissolved by the boiling alkali used in the isolation of the crude fibre. The boiling acid he found had little effect. Armstrong *et al.* [20] in England, Stallcup in America (Arkansas) [21], and Nordfeldt *et al.* in Sweden [22] have made similar analyses of crude fibre in temperate areas of the world but only Louw [23] in South Africa has reported any data from a semi-tropical country. The data of these workers are summarized in Table 1. Only the means and their standard errors are given and only graminaceous and leguminous whole plants or straws are included. Maize analyses are excluded from Norman's data. Each group of feeds has a similar lignin content and the mean recovery of lignin in crude fibre,[1] except for the feeds analysed by Louw, is similar though there is a very great variability. The recovery of lignin in the South African feeds is less than half of that in the others and the variability is very small. None of the other workers has analysed faeces in this manner but Louw found that the recovery of lignin in faeces derived from the feeds was almost the same. Louw's data are based on only four different feeds, all of which were hays, but if the difference is a general one occurring between two climatic zones, then there appears to be a

[1] The expression 'recovery of lignin' is used to mean the lignin in crude fibre expressed as a percentage of the lignin in the original material.

considerable difference in the properties of the lignins of plants in the two zones. Lignin in tropical feeds is probably more soluble in the alkali used to isolate crude fibre.

It is difficult to see how this difference in the two lignins could affect the digestibility of crude fibre in the animal. It is possible, however, that it could affect the calculation of the apparent digestibility coefficient. To illustrate how this is possible let us make a calculation based on hypothetical data.

TABLE 1. *Summary of Published Data giving the Recovery of Lignin in Crude Fibre (means and standard errors)*

Worker	*No. of samples*	*Crude fibre* %	*Lignin* %	*% lignin in crude fibre*	*% recovery of total lignin in crude fibre*
Feeds					
Norman [19] . .	7	32·7±2·4	10·8±2·3	12·8±3·0	35·5±5·9
Armstrong *et al.* [20]	8	25·7±2·4	7·2±1·0	7·8±1·8	32·7±7·3
Stallcup [21] . .	11	35·3±1·9	10·2±0·7	10·7±1·2	37·8±4·8
Nordfeldt *et al.* [22].	6	24·4±5·4	11·5±2·4	7·6±0·9	32·0±5·8
Louw [23] . .	4	35·5±1·1	10·4±0·9	5·2±0·1	14·6±1·1
Faeces					
Louw . . .	4	26·7±1·1	18·7±0·1	4·0±0·3	15·1±0·1

Consider a feed from the tropics with a value of 18·5 per cent. of lignin in crude fibre (e.g. the average of Louw's feeds, Table 1), and a feed from a temperate country with a value for lignin in crude fibre of 37·0 per cent. (e.g. the average of Stallcup's feeds, Table 1). Now, the apparent digestibility of crude fibre is given most simply by the expression: C.F. (feed)−C.F. (faeces), where C.F. (feed) is 100 parts of feed crude fibre ingested by an animal and C.F. (faeces) is the number of parts of faeces C.F. excreted for every 100 parts feed C.F. ingested. Each C.F. term consists almost entirely of a carbohydrate part (C) and a lignin part (L) so the coefficient may be written

$$C_{(\text{feed})}+L_{(\text{feed})}-C_{(\text{faeces})}-L_{(\text{faeces})}, \qquad (1)$$

where $C_{(\text{feed})}+L_{(\text{feed})} = 100$ and (if the crude fibre lignin is completely unchanged) $L_{(\text{feed})} = L_{(\text{faeces})}$.

For the tropical feed $L_{(\text{feed})} = 18{\cdot}5$ and therefore $C_{(\text{feed})} = 81{\cdot}5$.

Substituting these values in equation (1),

$$\text{Dig. coeff. C.F.} = 81{\cdot}5+18{\cdot}5-C_{(\text{faeces})}-18{\cdot}5.$$

If this hypothetical feed has a digestibility of crude fibre which is typical for tropical crude fibre, say the mean of those in Fig. 1, 62·5 per cent., then $C_{(\text{faeces})} = 19{\cdot}0$.

If we make the further assumption that the digestibility of the carbohydrate part of the crude fibre is universally the same we are now in a position to see what effect an increased recovery of lignin will have on the apparent digestibility of crude fibre.

Substituting in expression (1) for the temperate feed with $L_{(\text{feed})} = 37{\cdot}0$,

$$\text{Dig. coeff. C.F.} = 63{\cdot}0+37{\cdot}0-C_{(\text{faeces})}-37{\cdot}0.$$

Calculating $C_{(\text{faeces})}$ from the known digestibility of the crude fibre carbohydrate fraction of tropical grass,

$$C_{(\text{faeces})} = 63{\cdot}0\frac{19{\cdot}0}{81{\cdot}5} = 14{\cdot}7$$

$$\therefore \quad \text{Dig. coeff. C.F.} = 48{\cdot}3 \text{ per cent.}$$

The mean digestibility of C.F. in temperate areas (Fig. 1) is 50·0 per cent. Thus, given the digestibility of C.F. in the tropics and recovery of lignin in the two grasses, we have predicted the digestibility of C.F. in temperate areas.

This calculation is based on hypothetical data and involves assumptions which are, at the best, only approximations to the truth. It does, however, illustrate how this difference in the alkali solubility of lignin in two areas of the world can influence the calculation of the digestibility of crude fibre. Its effect is not on any biological process in the animal but is an artefact introduced by the technique chosen to isolate a crude-fibre fraction in the laboratory.

The digestibilities of crude fibre of the feeds in Table 1 were not known, and the conclusions are based on the analysis of only four tropical hays. This paper is an attempt to verify the difference in the properties of tropical and temperate lignin and crude fibre, using feeds for which the actual digestibility of the crude fibre is known.

Materials and Methods

Samples of dried grasses, hays, and straws, and of the faeces from animals which had been given these feeds, were obtained from Kenya and from the United Kingdom. Twenty samples of feeds and faeces from Kenya[1] consisted of local grasses and hays, mostly Rhodes, Kikuyu, and Cynodon, and oat, maize, and barley straws, and their corresponding faeces. Fifty-two samples from the U.K.[2] consisted of ryegrass-cocksfoot-clover mixtures from Edinburgh, dried grass and hays from Ayrshire, various mixtures of cocksfoot, timothy, fescue, ryegrass, hay, clover, and lucerne from Berkshire, hay and mixtures of ryegrass, cocksfoot, timothy, meadow fescue, and clover from Aberdeenshire, all with the corresponding faeces.

The content of lignin, crude fibre, and lignin in crude fibre, for each of these feeds and faeces was estimated. The method used for crude fibre was the standard A.O.A.C. method [24] with a correction for altitude [25] and lignin was estimated by the method of Moon and Abou-Raya [26] (a modification of Ellis, Matrone, and Maynard's method [27]) and was corrected for protein and ash. The crude-fibre estimation was made on 2 gm. of dried material, which provided sufficient

[1] For these materials I am indebted to Dr. A. Rogerson of the East African Veterinary Research Organization.

[2] For these samples I am indebted to: Dr. W. Moore, The North of Scotland College of Agriculture; Dr. P. McDonald, The Edinburgh and East of Scotland College of Agriculture; Dr. D. G. Armstrong, The Hannah Dairy Research Institute; Dr. W. F. Raymond, The Grassland Research Institute; Dr. M. J. Head, The National Institute for Research in Dairying; and Dr. J. Duckworth, The Rowett Research Institute.

crude fibre for a lignin estimation.[1] All figures used (except the methoxyl data) are the mean of two concordant estimations.

Results and Discussion

Table 2 shows the mean (and its standard error) of each value determined on feeds and corresponding faeces from the two countries. Neither the crude-fibre contents nor the digestibility coefficients of the crude fibre of the two groups of feeds are significantly different, although

TABLE 2. *Means (and their Standard Errors) from Analyses of U.K. and Kenya Grasses and Hays*

	Kenya	*U.K.*	*Significance of diff.*
Dig. coeff. C.F. . . .	66·4±2·2	62·5±1·7	N.S.
Feeds			
Crude fibre . . .	31·0±1·0	29·7±0·6	N.S.
Lignin in feed . . .	21·8±0·7	16·2±0·7	‡
C.F. lignin (% of crude fibre)	12·0±0·9	18·4±0·6	†
Recovery of lignin (%) .	17·4±1·5	29·7±4·7	‡
Faeces			
Crude fibre . . .	27·3±0·8	29·3±1·2	N.S.
Lignin in feed . . .	40·7±1·5	32·8±0·8	‡
C.F. lignin (% of crude fibre)	27·9±3·5	31·8±1·8	N.S.
Recovery of lignin (%) .	18·0±2·0	30·7±2·4	‡

N.S. = not significant at $P = 0.05$.
† = significant at $P = 0.01$.
‡ = „ „ $P = 0.001$.

the mean of the latter for the Kenya group is greater than that for the British group. The lignin content of the Kenya feeds is very significantly higher than that of the British group but even so the lignin in crude fibre of the Kenya group is lower, as also is the percentage recovery of lignin in crude fibre. The results confirm the suggestion that tropical lignin is more soluble than temperate lignin in the reagents used to isolate crude fibre. The percentage recoveries of lignin in the two groups of feeds are very similar to those given in Table 1, calculated from previously published data. The actual level of lignin in the crude-fibre is higher in the data reported here but this is probably a reflection of the higher levels of lignin in the original material.

The faeces derived from the feeds in the two groups show similar properties. The crude-fibre contents are not different and the lignin in the Kenya faeces is higher, as it is in the feeds. The figures for the percentage recovery of lignin are almost the same as they are for the feeds and the lignin in crude fibre is lower in the Kenya than in the British faeces although in this case the difference is not significant, largely because of a high variability which has appeared here.

[1] The lignins were powdered and estimated for methoxyl by the micro-Zeisel method.

These results thus confirm what was suspected from limited data in the literature, i.e. that there is a difference in chemical properties, probably alkali solubility, of lignin associated with different climatic regions of the world. Norman [19] observed a wide variation in the recovery of lignin in crude fibre in the materials he analysed. This is seen in the size of the standard errors in Tables 1 and 2. It is interesting that in both these tables the standard error of the lignin recoveries of both feed and faeces is greater for the temperate than for the tropical materials. In the particular grasses available for this experiment the lower recovery of lignin in crude fibre of the tropical grasses has been associated with a significant increase in the digestibility of crude fibre. But the Kenya feeds have a higher lignin content, and may be expected to have a lower digestibility than the U.K. grasses on this account.

By applying expression (1) above to each of the feeds, it is possible to test the assumptions made in the hypothetical calculation of the effect of varying lignin recovery on the apparent digestibility of crude fibres. Firstly, with neither the U.K. nor the Kenya feeds does the lignin in the feed crude fibre correspond to the amount of lignin in the equivalent amount of faeces crude fibre. For the Kenya feeds these amounts are, respectively, 12·0 and 9·4 parts (average), and for the U.K. feeds, 18·4 and 11·9 parts. The result of this is to reduce the magnitude of the effect of different lignin recoveries on the apparent digestibilities of crude fibre. Secondly, the digestibilities of the carbohydrate part of the crude fibre can be calculated from expression (1): the means are, for the Kenya feeds 72·5 per cent., and for the U.K. feeds 68·5 per cent., but the difference between the two groups, like that for the total crude-fibre digestibilities, is not significant.

The lignin which is not recovered in the crude fibre is included, in the proximate analysis of feedingstuffs, in the nitrogen-free-extract (N.F.E.). In tropical grasses where the recovery of lignin in crude fibre is low the recovery in N.F.E. will be correspondingly high. This may account for the low digestibility of the N.F.E. extract observed by workers in the tropics of whom Warth [2] was probably the first. The depressed digestibility of N.F.E. and the increased apparent digestibility of crude fibre in the tropics led to the first reports of feeds with a digestibility of N.F.E. lower than that of crude fibre coming from this part of the world. Not all the lignin associated with crude fibre in the feed remains associated with it in the faeces. This has been observed by Nordfeldt *et al.* [22] who found that some lignin passed from the crude-fibre fraction into the N.F.E.

The methoxyl content of every lignin was estimated and the means and standard errors of each group are given in Table 3.

No one of these mean methoxyl analyses is significantly different from any other.

Norman [28] was the first to show that the apparent lignin content of a feedingstuff was affected by the presence of certain proteins and carbohydrates. Each lignin isolated by any method using strong acid consists of a 'true lignin', derived from lignin in the original material, and a 'false lignin' derived from non-lignin materials by the action of

strong chemicals. These lignin values are corrected for protein but not for carbohydrate contamination. Methoxyl groups are associated mainly with the 'true lignin' [29] fraction and it was hoped that an estimation of methoxyl in the lignin of the feeds and faeces and of the crude fibre of these materials would give an estimate of the true lignin content. The only trend to be seen in the data is for the methoxyl content of crude-fibre lignin in Kenya feeds and faeces to be lower than the lignin from the whole plant. The difference approaches significance and may mean

TABLE 3. *Means (and their Standard Errors) of the Percentage of Methoxyl in the Lignin and Crude-fibre Lignin of Kenya and U.K. Feeds and in the derived Faeces*

	Feeds		*Faeces*	
	Lignin	*C.F. lignin*	*Lignin*	*C.F. lignin*
U.K.	2·64±0·18	2·59±0·26	3·03±0·18	2·85±0·26
Kenya	3·16±0·38	2·01±0·39	3·36±0·40	2·25±0·38

that in these feeds the methoxyl-containing lignin is more soluble in the crude-fibre reagents than it is in the U.K. feeds as is the case with total lignin.

Acknowledgements. The author is indebted to Dr. E. W. Russell of E.A.A.F.R.O. and to Dr. J. Duckworth of the Rowett Research Institute for encouragement and invaluable discussion.

REFERENCES

1. J. C. BRUNNICH and V. S. RAWSON, *Queensland Agric. J.*, 1921, **15**, 195, 235.
2. F. J. WARTH, *Mem. Dept. Agric. India, Chem.*, 1926, **9**, 37.
3. —— and F. J. GOSSIP, ibid., 1928, **10**, 1.
4. ——, ibid., 1930, **11**, 53, 73, 85.
5. P. E. LANDER and L. C. DHARMANI, ibid., 1924, **7**, 77; 1927, **9**, 63; 1928, **9**, 235; 1929, **10**, 169, 181; 1930, **10**, 193.
6. E. W. CRAMPTON and R. P. FORSHAW, *Sci. Agric.*, 1939, **19**, 701.
7. F. W. CHRISTENSEN and J. H. HOPPER, *N. Dak. Agric. Exp. Sta.*, Tech. Bull. 260, 1932.
8. H. E. WOODMAN and R. E. EVANS, *J. Agric. Sci.*, 1930, **20**, 587.
9. J. DUCKWORTH, *Trop. Agric.*, Trin., 1946, **23**, 4.
10. M. H. FRENCH, *J. Agric. Sci.*, 1940, **30**, 503.
11. R. E. HUNGATE, G. D. PHILLIPS, G. D. HUNGATE, and A. MACGREGOR, ibid., 1960, **54**, 196.
12. J. QUARTERMAN, G. D. PHILLIPS, and G. H. LAMPKIN, *Nature*, Lond., 1957, **180**, 552.
13. M. H. FRENCH, *Herb. Abs.*, 1957, **27**, 1.
14. H. E. WOODMAN, *Rations for Livestock*, Bulletin 48, London, H.M.S.O., 1948.
15. —— *et al.*, *J. Agric. Sci.*, **13**, 483; **18**, 266, 544; **19**, 236; **20**, 53; **21**, 267; **22**, 852; **23**, 419; **24**, 283, 575; **25**, 50; **30**, 189; **34**, 35.
16. J. R. TODD, ibid., 1956, **47**, 35, 225.
17. A. ROGERSON, *E. Afr. Agric. J.*, 1955–6, **21**, 3, 159.
18. M. H. FRENCH, *Empire J. Expt. Agric.*, 1954, **24**, 53.
19. A. G. NORMAN, *J. Agric. Sci.*, 1935, **25**, 529.
20. D. G. ARMSTRONG, H. COOK, and BRYNMOR THOMAS, ibid., 1950, **40**, 93.
21. O. T. STALLCUP, *J. Dairy Sci.*, 1958, **41**, 963.

22. S. Nordfeldt, O. Svanberg, and O. Claesson, *Acta Agr. Suecana*, 1949, **3**, 135.
23. J. G. Louw, *Onderstepoort J. Vet. Sci.*, 1941, **17**, 165.
24. Association of Official Agricultural Chemists (U.S.A.), *Official Methods of Analysis*, 7th ed., 1950.
25. H. W. Dougall, *Nature*, Lond., 1955, **175**, 952.
26. F. E. Moon and A. K. Abou-Raya, *J. Sci. Food Agric.*, 1952, **3**, 407.
27. G. H. Ellis, G. Matrone, and L. A. Maynard, *J. Anim. Sci.*, 1946, **5**, 285.
28. A. G. Norman, *Biochem. J.*, 1934, **28**, 2147, 2160.
29. R. M. Forbes and W. P. Garrigus, *J. Anim. Sci.*, 1950, **9**, 354.

(*Received 1 March 1960*)

THE DEVELOPMENT AND BODY COMPOSITION OF DOCKED AND UNDOCKED FAT-TAILED AWASI LAMBS

H. EPSTEIN

(*Faculty of Agriculture, Hebrew University, Jerusalem*)

WITH PLATE 2

Summary

Twelve male fat-tailed Awasi lambs were docked three days after birth, and twelve similar lambs were left undocked as controls. The lambs were weighed at birth and at regular intervals until they were slaughtered on the ninety-first day.

The carcasses were divided into forequarters and hindquarters, and the head, legs, edible internal organs, and skin were weighed separately. The forequarters and hindquarters were dissected into bone, muscle, and fat tissue, which were also weighed separately.

Docking retarded the growth of the lambs during the first month, and also very slightly during the second and third months.

Nearly all the loss of the fat that would normally be stored in the tail was compensated by the greater amount of muscle and fat tissue in the carcasses of the docked lambs, especially in the hindquarters. The conformation, from the mutton point of view, of the docked lambs and their carcasses were superior to those of the undocked lambs.

The content and proportions of the blood-serum proteins and lipoproteins was not affected by the docking.

The disadvantages due to docking, namely the additional work entailed, the slight retardation in growth, and the slightly lower killing percentage, were compensated by a superior carcass. In terms of money, they would be compensated by an increase of approximately 5 per cent. in the live-weight price.

THE aversion to fat meat is so strong among meat consumers in Israel that during the summer months considerable quantities of sound animal fat have to be sold to soap factories or as pig feed. This tendency is particularly marked in the general objection to the fat tail of the local Awasi lamb, which constitutes a considerable part of the carcass; in an earlier test with ten 3-month-old male Awasi lambs it was shown to weigh 1·6 kg. on an average, or 11 per cent. of the total average dressed carcass weight [1]. In the present experiment the share of the fat tail was even higher, 14 per cent. During the last two years the wholesale value of fat tail has fallen from par to one-third of the value of the rest of the carcass, including lungs, liver, heart, spleen, kidneys, and testicles; and it would be still lower had sausage manufacturers not found a satisfactory way of using tail fat in some of their products.

In a previous test the author [2] had docked fat-tailed lambs in connexion with a theoretical problem concerning the descent of the fat-rumped from the fat-tailed type of sheep. The present experiment was undertaken to answer a number of practical questions involved in the docking of the fat tail: (1) Does the operation retard the development of the lamb? (2) Is the energy stored in the fat tail lost in the docked lamb, or does it appear in other parts of the body? (3) Does it appear there as fat or in other kinds of tissue, such as muscle and bone? (4) Does it pay the breeder to dock the fat tail?

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

The lambs were tested for three months only. In an experiment with male Corriedale and Rambouillet lambs it had been found that the growth-rate of lambs kept on natural pasture in Israel is not sufficiently high after the third month of age to warrant slaughter being delayed [3]. Also, lamb prices in this country drop with the onset of the hot season and the reduced demand for meat in the early summer. Again, butchers prefer a small to a large lamb.

Description of Awasi Sheep

The Awasi is the common breed of sheep in central and western Iraq, Syria, the Lebanon, Jordan, and Israel. In the last-mentioned country it has been considerably improved with a view to milk production, so that some flocks now produce an average of 400–550 kg. of milk per lactation, with 7 per cent. butter-fat. The breed is distinguished by a large, broad fat tail and a fleece of coarse carpet wool. The live-weights of improved adult rams and ewes average 74 and 50 kg. respectively.

The twenty-four lambs used in the present trial were all sired by the same ram. The dams of sixteen lambs were aged ewes selected for former high twinning performance; they had previous maximum milk records ranging from 278 to 460 kg. The dams of the remaining eight lambs were progeny of these ewes.

Experimental Procedure

The present study was made with male fat-tailed Awasi lambs over two seasons—1957–8 and 1958–9; in each season the number of docked and undocked lambs was the same.

The new-born lambs, twins included, were arranged in pairs. One of each pair was selected at random and docked; the other was left undocked for control. While two pairs of male twins were thus separated, one of each pair being docked, three male lambs with twin sisters chanced to be included among the undocked controls.

The lambs and their dams were kept on natural pasture in an uprooted orange grove from approximately 8 a.m. until 3 p.m. The pasture consisted mainly of *Avena sterilis*, *Bromus* sp., *Phalaris paradoxa*, and *Avena byzantina*, *Trifolium* sp., *Medicago hispida* and *Tetragonalobus palaestinus*, and *Polygonum equisetiforme*. After their return from pasture and throughout the night the animals had free access to drinking water and a salt lick. The ewes received an additional concentrate ration of 300 g. per head, while the lambs had access to a similar concentrate mixture in a creep. The ewes were not milked, suckling their lambs throughout the trial.

The lambs were weighed at birth, and on the following 3 days at the same hour. On the third day after birth half the lambs were docked, immediately after weighing, being already fairly strong to stand docking, while the lateral skin folds of the tail were still empty of fat. The operation is easy; the folds on either side of the tail are cut with a scalpel in the direction of the tail butt, as close to the body as possible (since small remnants of skin folds turn later into large reservoirs of fat). This part of the process causes the loss of only a few drops of blood. The tail is

then docked between the first and second caudal vertebrae. In order to prevent an undue loss of blood, a loop of string may be tied around the tail butt prior to docking, to be removed an hour or so after the operation. The wound is dusted with an antiseptic powder. No lambs died as a result of the operation, although some showed discomfort for the rest of the day. The weight of the docked tail was recorded. Daily weighing of the lambs was continued for 3 more days, and thereafter on the 14th, 21st, 30th, 60th, and 90th day after birth. The lambs were then deprived of feed for 18 hours, weighed empty, and slaughtered on the 91st day.

At the time of slaughter 10 ml. of blood were taken from six of the docked and four of the undocked lambs, for analysis; the ten lambs included the two pairs of male twins referred to above.

The following weights were recorded: pelt including the skin of the legs, head, and ears; head including tongue and brain; legs, liver, lungs, spleen, heart, kidneys, testicles, diaphragm with oesophagus, trachea, and thymus.

The carcass was cut behind the last rib into two parts, which were weighed; in the undocked lambs the fat tail was included in the weight of the hindquarters.

The forequarters and hindquarters were then dissected into bone, muscle, and fat tissue. The connective tissue was not weighed separately, but with the part to which it belonged. In the undocked lambs the fat of the fat tail, and the tail consisting of twelve vertebrae, musculature and tendons, were weighed separately. The weight loss encountered in the course of the dissection was recorded.

Results

The data are recorded in the following tables:

TABLE 1. *Mean Live-weights of Twelve Docked and Twelve Undocked Male Awasi Lambs (kg.)*

Age in days	*Docked*		*Undocked*	
	Mean	*S.D.* ±	*Mean*	*S.D.* ±
Birth	5·1	0·50	4·5	0·57
1	5·4	0·48	4·7	0·58
2	5·6	0·63	5·1	0·68
3	5·9	0·78	5·5	0·70
Weight of docked tail	0·124	0·03	..	..
4	5·7	0·67	5·9	0·70
5	6·0	0·76	6·1	0·68
6	6·3	0·76	6·4	0·79
14	8·0	1·21	8·5	0·87
21	9·8	2·11	10·4	1·50
30	12·6	2·92	13·1	2·23
60	21·3	4·52	22·0	2·62
90	29·9	5·98	30·8	3·30
91	27·2	5·70	27·5	3·26

TABLE 2. *Average Daily Weight Increase of Twelve Docked and Twelve Undocked Male Awasi Lambs (gm.)*

Period	Docked		Undocked	
	Mean	S.D. ±	Mean	S.D. ±
1st month . . .	250	88·0	287	65·2
2nd ,, . . .	290	61·7	297	56·0
3rd ,, . . .	287	68·1	293	55·8

TABLE 3. *Mean Weights (in kg. and in % of mean live-weights) of Carcass, Head, Feet, Inner organs, and Pelt, of Twelve Docked and Twelve Undocked Male Awasi Lambs*

Part	Docked			Undocked		
	kg.	S.D. ±	in % of live wt. (27·2 kg.)	kg.	S.D. ±	in % of live wt. (27·5 kg.)
Total carcass .	13·59	3·69	50·0	13·87	2·45	50·4
Forequarters .	6·96	1·73	25·6	6·48	0·90	23·6
Hindquarters .	6·64	1·97	24·4	7·39	1·61	26·8
Head . .	1·23	0·18	4·5	1·17	0·08	4·2
Feet . .	0·58	0·08	2·1	0·58	0·06	2·1
Liver . .	0·47	0·11	1·7	0·49	0·05	1·8
Lungs . .	0·36	0·11	1·3	0·32	0·05	1·2
Spleen . .	0·06	0·01	0·2	0·05	0·01	0·2
Heart . .	0·12	0·02	0·5	0·12	0·02	0·4
Kidneys . .	0·10	0·01	0·4	0·10	0·02	0·4
Testicles . .	0·04	0·02	0·2	0·04	0·02	0·2
Diaphragm, &c.	0·39	0·10	1·4	0·33	0·07	1·2
Total edible inner organs .	1·54	0·28	5·7	1·45	0·17	5·4
Pelt . .	3·63	0·62	13·3	3·76	0·72	13·7

TABLE 4. *Mean Weights (in kg. and in % of mean live-weights) of Bone, Muscle, and Fat Tissue in Forequarters, Hindquarters, and Total Carcass of Twelve Docked and Twelve Undocked Male Awasi Lambs*

	Docked			*Undocked*		
Part	*kg.*	*S.D.* ±	*in % of live wt. (27·2 kg.)*	*kg.*	*S.D.* ±	*in % of live wt. (27·5 kg.)*
Forequarters						
Bone	1·45	0·29	5·3	1·45	0·19	5·3
Muscle	4·10	0·76	15·1	4·01	0·47	14·6
Fat tissue	1·34	0·77	4·9	0·94	0·34	3·4
Weight loss	0·07	0·04	0·3	0·08	0·04	0·3
Total	6·96	1·73	25·6	6·48	0·90	23·6
Hindquarters						
Bone	1·03	0·20	3·8	1·00	0·10	3·6
Muscle	3·51	0·73	12·9	3·35	0·40	12·1
Body fat tissue	2·04	1·12	7·5	1·03	0·35	3·7
Tail fat	..	..	..	1·90	0·90	6·9
Tail	..	..	..	0·07	0·02	0·3
Weight loss	0·06	0·03	0·2	0·04	0·03	0·2
Total	6·64	1·99	24·4	7·39	1·61	26·8
Total carcass						
Bone	2·48	0·47	9·1	2·45	0·29	8·9
Muscle	7·61	1·47	28·0	7·36	0·82	26·7
Body fat tissue	3·37	1·87	12·4	1·97	0·68	7·1
Tail fat	..	..	..	1·90	0·90	6·9
Tail	..	..	..	0·07	0·02	0·3
Weight loss	0·13	0·06	0·5	0·13	0·03	0·5
Total	13·59	3·69	50·0	13·87	2·45	50·4

The blood serum of six docked and four undocked lambs was analysed for total protein (albumin and globulin) and cholesterol, and for the paper electrophoric distribution of proteins and lipoproteins, with the following results (Tables 5 and 6).

TABLE 5. *Chemical Analysis of Blood Serum of Six Docked and Four Undocked Male Awasi Lambs, for Proteins and Cholesterol*

	Docked		*Undocked*	
Serum contents	*g./100 ml. serum*	*S.D.* ±	*g./100 ml. serum*	*S.D.* ±
Albumin	3·83	0·24	3·80	0·18
Globulin	2·08	0·18	2·05	0·25
Total protein	5·91	0·29	5·85	0·43
	mg./100 ml. serum	*S.D.* ±	*mg./100 ml. serum*	*S.D.* ±
Total cholesterol	79·8	5·6	80·7	7·2

TABLE 6. *Paper Electrophoric Distribution of Proteins and Lipoproteins in Blood Serum of Six Docked and Four Undocked Male Awasi Lambs*

Proteins	*Docked*		*Undocked*	
	in % of total proteins	*S.D.* ±	*in % of total proteins*	*S.D.* ±
Albumin . .	61·16	4·08	61·00	0·94
α_1-Globulin . .	2·40	0·58	2·37	0·37
α_2- ,, . .	3·83	0·69	4·25	0·57
α_3- ,, . .	11·83	2·10	10·80	0·47
β_1- ,, . .	4·50	1·34	4·59	0·93
β_2- ,, . .	3·08	0·29	5·62	0·58
γ- ,, . .	13·20	2·56	11·37	1·20
Lipoproteins	*in % of total lipoproteins*	*S.D.* ±	*in % of total lipoproteins*	*S.D.* ±
Albumin-bound lipoprotein . .	47·90	3·22	44·75	2·68
α-Lipoprotein . .	19·00	2·67	22·00	3·14
β- ,, . .	12·00	1·08	12·15	2·15
γ- ,, . .	21·10	1·96	21·10	3·47

Discussion

The docking of the fat tail had a small negative effect on the weight of the lambs at all periods. Although the actual loss in weight (by docking) occurred on a single day, the lambs never fully recovered the relapse in comparison with the undocked controls. Docking materially affected the average daily weight increase during the first month, the difference being 37 g. in favour of the undocked lambs; the disadvantage, while persisting, fell to a daily average of 7 g. during the second month, and 6 g. during the third. Altogether the retrogression was slight, the weight difference at the age of 91 days amounting to only 300 g., i.e. about 1 per cent. of the weight of the undocked lambs. Nevertheless, the retardation in growth caused by docking was not immaterial in view of two circumstances: (1) The average birth-weight of the undocked lambs was 600 g. below the average of the lambs to be docked (but still 400 g. above the breed average, which is 4·6 kg. for single, 3·8 kg. for twin male lambs); on the third day, shortly before docking, the mean weight difference, though reduced by one-third, was still 400 g. in favour of the lambs to be docked. Underwood *et al.* [4] have recorded that, in Western Australia, lambs heavier at birth grew significantly faster than those lighter at birth, each 1 lb. increase in birth-weight reducing the time necessary to reach 65 lb. live-weight by 4½–5 days. (2) Among the undocked lambs there were three more twins, which had to share their dams' milk (though this was plentiful) with their sisters.

The weights attained by both groups at different ages, save for the docked animals during the first month, correspond with the normal

weights of well-fed single male Awasi lambs. Thus, 39 male lambs of this breed, reared on well managed farms up to the age of 8 weeks, showed an average daily gain of 281 g. [5]; this compares with 270 g. for the docked lambs, and 292 g. for the controls in the present trial. During the first 4 weeks, the same 39 lambs gained an average of 301 g., and during the following 4 weeks an average of 262 g. per day, as compared with respectively 250 and 290 g. for the docked, and 287 and 297 g. for the undocked lambs, in the present test.

In a feeding trial at Acre Government Stock Farm, male Awasi lambs, fed on a low-level ration for 4 weeks after normal weaning, weighed 24·18 kg. at 12 weeks of age; and those fed on a high-level ration—29·44 kg. [6]; this compares with 29·90 for the docked, and 30·80 kg. for the undocked lambs at the age of 90 days in the present experiment.

While docking thus had a slight negative effect on weight, the mutton conformation of the live docked lambs was superior to that of the undocked controls. In particular, the forequarters and hindquarters had a more balanced appearance, approaching the conformation desired in a mutton breed. Outwardly there was little evidence of fat accumulation on both sides of the tail butt.

During the 18 hours fasting period prior to slaughter, the docked lambs lost 2·7 kg. or 9 per cent., the undocked controls 3·3 kg. or 10·7 per cent., in live-weight.

In the slaughtered lambs there was hardly any difference between the docked and the undocked in the average weight of the head, feet, and edible internal organs. The slightly larger weight of the heads in the undocked lambs may have been due to fortuitous differences in horn weight; there were nine horned and three polled lambs in each of the two groups. The relative weight of the feet was the same in both groups. In the docked lambs the mean weight of the edible organs was 86 g. above that of the controls. The skin of the docked lambs weighed 133 g. less on an average than the skin of the undocked lambs, due to the presence of the tail covering in the latter.

The dressing (killing) percentage of the docked lambs was 50, that of the undocked lambs 50·4. Docking had, however, a marked influence on the weight ratio of forequarters to hindquarters. The forequarters of the docked lambs were absolutely and relatively heavier than the forequarters of the undocked lambs. Similarly, and to a greater extent, the hindquarters of the docked lambs were absolutely and relatively heavier than the hindquarters of the undocked lambs *minus* the fat tail, though the difference in favour of the docked lambs was less than the weight of the fat tail (1·97 kg.).

The forequarters of the docked lambs were 317 g. or 4·8 per cent. heavier than the hindquarters. The forequarters of the undocked lambs were 916 g. or 12·4 per cent. lighter than the hindquarters including the fat tail; but they were 1,056 g. or 19·5 per cent. heavier than the hindquarters *minus* the fat tail—a very undesirable proportion from the mutton point of view. Taking the weight of the forequarters as 100, the ratio of forequarters to hindquarters was as follows:

Group	*Forequarters*	*Hindquarters*
Docked lambs	100	95·4
Undocked lambs including fat tail . . .	100	114·1
Undocked lambs excluding fat tail . . .	100	83·7

The carcasses of the docked lambs had a superior appearance to those of the undocked controls, although in several of the former accumulation of fat on both sides of the tail butt detracted from their appearance. The superiority of the docked carcasses was due to the better condition and more favourable balance of the forequarters and hindquarters. The hindquarters of the docked lambs, more especially the thighs and buttocks, were fuller and heavier than those of the undocked; they were thus superior in economic usefulness since to the consumer the legs of mutton and the loin chops are the best part of the sheep [6]. See Plate 2.

The loss in carcass weight caused by docking was much less than the weight of the fat tail. Additional nutrients in amounts not far short of those normally stored in the tail of fat-tailed lambs, were deposited in the docked lambs in both the forequarters and the hindquarters. Dissection demonstrated in which forms this deposition had taken place.

In the forequarters the proportion of bone to live-weight was not affected by the docking of the fat tail. But muscle tissue in the forequarters of the docked lambs exceeded that of the undocked controls by 94 g., fat tissue by 392 g. In other words, the fat, which would normally have been deposited in the tail, was partly made good by deposition of extra muscle and extra fat in the forequarters in the ratio of 1 : 4·2. In terms of live-weight, the percentages of lean meat and fat in the forequarters of the docked lambs exceeded those for the undocked lambs by 0·5 (15·1 as against 14·6) and 1·5 per cent. (4·9 as against 3·4) respectively. However, only about one-fourth of the fat normally in the tail was represented by the extra meat and fat in the forequarters of the docked lambs.

In the hindquarters, bone growth was affected by docking to a negligible extent, the bone in the docked lambs weighing 33 g. more than in the undocked. But the growth of muscle and body fat tissue was markedly increased by docking; in the docked lambs the lean meat weighed 162 g. more, and the body fat tissue 1,004 g. more, than in the undocked. In the docked animals the fat that would normally have been deposited in the tail was partly made good by deposition of extra muscle and extra fat in the hindquarters, in the ratio of 1 : 6·2. In terms of live-weight, the hindquarters of the docked lambs contained 0·8 per cent. (12·9 as against 12·1) more muscle tissue, and 3·8 per cent. (7·5 as against 3·7) more body fat than the hindquarters of the undocked controls. Approximately three-fifths of the 'inhibited' tail fat was made good by extra meat and fat in the hindquarters of the docked lambs, the share of the hindquarters as a depository of the extra meat and fat deposited thus being 2·4 times that of the forequarters. Were it possible, in docking the fat tail under conditions of ordinary farm management, completely to remove the skin folds on both sides of the tail, the two fat

cushions near the butt of the tail would be of negligible size in the 91-day lamb, and the ratio of extra muscle to extra fat tissue deposited in the hindquarters following docking would probably be as narrow as that for the forequarters.

The ratio of lean meat to total fat was 2·26 : 1 in the whole carcass of the docked lambs, and 1·91 : 1 in that of the undocked controls. As it is the protein of muscle that gives meat its special nutritional value, the superiority of the docked to the undocked carcasses was to some extent due to the higher relative share of lean meat. In terms of money, it is estimated that the live-weight price received for docked male lambs of this size and age should be about 5 per cent. above that for undocked.

The very slight and statistically not significant differences in the protein and cholesterol contents of the blood serum and in the paper electrophoric distribution of the protein and lipoprotein patterns between the docked and undocked lambs indicate that the synthesis of the blood serum proteins and lipoproteins was not affected by the docking of the fat tail. This conforms with the almost equal liver-weights of both groups as well as with the high rate of body-fat accumulation in the docked lambs, which nearly counterbalanced the inhibited tail fat.

Acknowledgement. The author is indebted to Dr. K. Perk and Mr. K. Lobel, Faculty of Agriculture, Rehovot, for the blood analyses.

REFERENCES

1. H. Epstein, *Refuah Veterinarith*, 1957, **14**, 101.
2. —— *E. Afric. Agric. J.*, 1957, **23**, 42.
3. —— *The Development of Corriedale and Rambouillet Lambs on Natural Pasture in Israel*, Bull. Res. Counc. Israel, B, 1958, **7B**, 191.
4. E. J. Underwood, F. L. Shier, and H. G. Cariss, *J. Dept. Agric. West. Australia*, 1943, **20**, 288.
5. D. Becker, *Sheep Breeding* (Hebrew), Israel, Merhavia Press, 1958.
6. M. Finci, *The Improvement of the Awassi Breed of Sheep in Israel*, Jerusalem, Weissmann Science Press, 1957.
7. A. Fraser, *Sheep Husbandry*, London, Crosby Lockwood, 1954.

(*Received 23 April 1960*)

Carcass of docked fat-tailed lamb
(weight 14·650 kg.)

Carcass of fat-tailed lamb
(weight 14·950 kg.)

Tail of fat-tailed lamb, with fat
cushion removed (weight 70 g.)

A RECORD OF COTTON BREEDING FOR THE LAKE PROVINCE OF TANGANYIKA: SEASONS 1939–40 TO 1957–8

J. E. PEAT AND K. J. BROWN

(*Empire Cotton Growing Corporation, Ukiriguru, Lake Province, Tanganyika*)

Summary

The cotton-breeding work for the Lake Province of Tanganyika over nineteen seasons, from 1939–40 to 1957–8, has been, essentially, selection from a mixed plant population, where natural crossing and segregation had been occurring for decades before the programme was started. Much that was unexpected has shown up. An important feature has been the large amount of single-plant material, and reselections from the best of this, that has been tested and later relegated, to achieve one pre-eminent family; this was from a reselection made nine seasons after the selection programme had started, out of segregating material from a straight selection out of MZ.561 made five seasons after the programme had started.

There have been five multi-line seed issues since the issue of MZ.561 in late 1939. Each issue has shown generally a lint yield improvement over the previous issues. UK.55, in fifty 'valid trials'[1] over four seasons, for the Province as a whole, showed a mean increase over MZ.561 of 31 per cent., 93 lb. of lint/acre/year —just under one-quarter of a bale. There have been very considerable variations from season to season, and from area to area, in the extent of yield improvement effected.

Percentage increases from poor land, with yields nearer the general level of the African cultivator, have been generally better than from well-farmed trials on richer land, though the *total lint yield increases* can be the greater from the higher level of yields. The benefits from the strain issues have been greater in the more difficult middle and south of Sukumaland than in the better Lake-shore areas.

'AND it is therefore not surprising that the successes of our plant breeders have rather been due to *the accommodating nature of their material*, than to the employment of genetical ideas which might have helped them to get there sooner and get there quicker' [1].

The area in the Lake Province of Tanganyika concerned with cotton growing amounts roughly to 12,000 to 15,000 square miles; the maximum acreage yet planted to cotton has been reported as over 400,000 acres, planted by nearly 250,000 growers. The type of country, climate, and the agricultural conditions have been described in a number of papers; amongst them: Peat and Prentice [2, 3], and in Malcolm's study of rural problems in Sukumaland [4]. The general elevation of the cotton-growing areas is from just over 3,700 to about 4,500 feet. The soils are mainly of granitic origin; in much of the area, as at Ukiriguru, there is a clearly defined soil catena. The hill sands, on which much cotton is grown, are deep fairly coarse sandy loams with pH values of 6·0 to 7·0; they are very fertile on first cultivation, but after years of cultivation they decline in

[1] 'Valid trials' are those with a coefficient of variation of 25 per cent. or less.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

fertility and then become very responsive to fertilizer treatments. Cotton is planted on ridges, 5 feet apart, and (at least for all experimental testing) the furrows are tied by tie-ridges about every 8 feet, making rain-holding basins.

The Ukiriguru plant-spacing on these ridges is two rows per ridge, 18 in. between hills, leaving two plants per hill, giving just over 11,000 hills per acre, and a maximum possible plant population of just over 23,000 per acre; in practice, the plant population would probably range more around 15,000 per acre.

The valley-bottom soils, 'Mbuga', black calcareous sandy clay, are 'chemically fertile but physically difficult', pH values 7·5 to 8·5. There, cotton is planted on the flat, at 3 feet between the rows, 18 in. between plants in the row. There is a similar row spacing at Lubaga, the sub-station just outside Shinyanga, on 3-foot ridges.

Ukiriguru, where most of the work has been done, is 17½ miles south of Mwanza on Lake Victoria. Lubaga is about 80 miles south from Ukiriguru, but in completely different country, drier, hotter, and with different soils.

The rainy season extends from late October until mid-May, with a mean rainfall at Ukiriguru of about 30 in. December is the month recommended for cotton planting. Rainfall is heavier along the Lake shore, lighter to the south of the Province, and there tends to cut off slightly earlier. Much of the rain comes from localized thunder storms rather than in a general downpour, resulting in unevenness of distribution. Heavy storms—say over 2 in. in 24 hours—are more common in the south of the Province than at Ukiriguru. There are not clearly demarcated short and long rains, but in most years there is a 'pinch' in the rainfall in mid season, which can occur late in January, or in February, or much less often in March. The Ukiriguru annual rainfall over the last twenty-seven years has ranged from 20·52 to 52·87 in. (52·87 and 20·75 in. in successive years). At the end of the rains, pronounced drying winds from the south-east, from the dry region of the central Province, bring about leaf shedding and a cessation of cropping. The onset of these drying winds varies from year to year, and is one of the factors determining the setting of a top crop.

Temperature ranges are not great, with mean maxima at Ukiriguru during the growing season of 82 to 84° F., and mean minima of 63° F. In the south of the Province maximum temperatures are about 3° higher. In July, the coldest month at Ukiriguru, the mean minimum drops to about 58° F.

Lake Province Foundation Cotton Seed Stocks

Harris [5] has reported that cotton growing in the Lake Province of Tanganyika started about 1904, with seed imported from Uganda. There was a fresh introduction of seed from Uganda in 1921, by the newly formed Department of Agriculture, Tanganyika. It is reported that there were subsequent introductions of Uganda seed. Egyptian seed had been introduced by the Germans. There was evidence of *barbadense* characters in Ukerewe 'Local' cotton, when the first-named

author in 1940 first visited Ukerewe Island, then the richest cotton-growing area, with a good rainfall.

The imported Uganda seed [6] would have been of mixed origin, producing a heterogeneous range of plant types. Varieties Allen, Sunflower, and Griffen (from the United States), and Floradora (through 'Nyasaland Upland'), would have been represented, in what became known as Mwanza 'Local'. There would have been natural crossing and segregation decades before selection was started at Ukiriguru. With the harder growing conditions and the seasonal hazards of the Lake Province, the natural selection pressure would have been towards a range of tougher plant types than in much of Uganda.

In the 1939/40 season, when Mwanza 'Local' was the cotton being grown throughout the Lake Province, a start was made with a first multiplication of two strains, MZ.561 and MZ.457, each only one generation away from Mwanza 'Local', which had been selected and tested by the late D. Thornton and the late N. V. Rounce, several years before.

Cotton Seed Introductions

U.4 Selections

In the 1939–40 season a range of Barberton (eastern Transvaal), and Gatooma (Southern Rhodesia), jassid-resistant U.4 strains, which were a success in their home areas, were grown at Ukiriguru and at Lubaga, as types likely to fit into the Lake Province environment and be a basis for further selection. It was a surprise to the first-named author, and to F. R. Parnell, how indifferently they behaved in general, compared to their behaviour in their home areas. (One lesson that it is difficult for a plant breeder to learn is that his pet strains need not be a success away from their home area, though the environments may not appear to be markedly dissimilar.) One reason now becoming more obvious is that in this instance the U.4 strains had been selected partly for fairly early maturity—for planting, much as in the Lake Province, in November into December, but with cropping completed because of low temperatures by around mid-May—a 5 to 6 months' season. In parts of the Lake Province the cropping period in some seasons may extend to nearly 8 months, allowing for top-crop setting, and recovery from any setback.

It was not until 1943 that at Ukiriguru and Lubaga the attempt to get acclimatized segregates from the U.4 material was given up. Apart from inadequate cropping, they had not the lint qualities of the accepted AR Mwanza. Barberton U.4 strains, U.4/4/2, and U.4/998, had been tried out in the Shinyanga district in 1929–30, and two seasons later provided the seed stock for that district. They were later replaced by the better-yielding, higher-quality MZ.561. Barberton and Gatooma U.4 × MU.8 hybrid strains continued to be tested until 1950.

Barberton Sea Island × U.4 Segregates [7]

F. R. Parnell at Barberton before the war had started a programme, inbreeding the descendants of an Upland (U.4) × Sea Island cross. In

1944 the first-named author obtained seed from two of the best-looking single plants with good jassid resistance. The descendants of one lot, A.3315, were continued at Ukiriguru; at first only a few of the most likely plants were selfed each season to constitute a Special Bulk; the remainder—and there was some complete rubbish amongst them—were discarded. By 1947 there was a reasonable single-plant lot, S/6/4. Four generations later two strains, 1/685 and 1/686 (selected in 1951), in trials in 1954–5, and 1/686 in 1956–7, were amongst the top yielders, and appreciably better than MZ.561: in 1955, +37 per cent. in mean lint yield at Ukiriguru, compared to MZ.561, and +26 per cent. from nine district plots; 1/686 in 1957 gave a mean increased lint yield, compared to MZ.561, of +38 per cent. from seven inland district plots, and +14 per cent. from four Lake-fringe district plots. Arnold [8] records the good bacterial-blight resistance of 1/686. The possibility of this material having arisen by some chance cross-pollination cannot be entirely eliminated, but this is considered unlikely.

A later descendant, 6/5, selected in 1956 out of 1/686, was not easily distinguishable from Ukiriguru strains; it was essentially a '*hirsutum*' type, but with slightly better lint. It was considered as a 'possible' for inclusion in the issue UK.58; but being of non-Mwanza 'Local' origin it was considered that further testing was required.

Jassid Resistance

The first requisite in selection from Mwanza 'Local', MZ.561, and MZ.457, was to obtain jassid resistance [9]. Jassid resistance has been shown to be leaf-hair mechanical resistance—an interference with ovipositing. Length of the leaf hairs on the under surface of the leaf, and their density, are equally important. There is poorer leaf-hair expression, and therefore less jassid resistance, under poor growing conditions. In the Lake Province, jassid attack has varied considerably in severity from year to year. On looking back, in the earlier years there had been a tendency in selection to relax, after a year or two of lighter jassid attack, and to permit the continuing of better-yielding, higher-quality strains, which were not quite good enough for jassid resistance.

Selection Methods

In the early years of selection African recorders, as a first step, marked in all bulks any plants having good leaf hair. The best of these were grown in the following year as progeny lots. It proved painstakingly difficult to find single-plant progenies with good leaf hair allied to reasonable cropping and lint qualities. It was thought at first that there might be a linkage between the genes allowing of leaf hair expression and the genes determining shortness and harshness of lint. Practically all the earlier strains with good jassid resistance had to be discarded because of a tendency to shorter and harsher lint than the accepted AR Mwanza standard. It seemed at first doubtful whether the combination of good leaf hair, lint length, and the characters which make for AR Mwanza spinning quality was to be obtained.

It is not suggested that in the early years all 'possible' plants in bulks of 'Local' and MZ.561 would have been marked; but the numbers marked were high, running into thousands per year in the early years. Possibly only one in, say, ten of these, or less, would have been retained for first growing as a single-plant progeny.

It was the judgement on these progenies that gave the first assessment; but this first assessment was not in itself enough.

As the work progressed, reselection within the most promising progenies became the major portion of the programme. (But, as will be discussed later, it was a selection made directly out of MZ.561, in the *fifth* season of the programme, that became the progenitor of the present premier Ukiriguru stocks.) The number of single-plant progeny lots grown varied from year to year, from about 300 to over 600.

The single plant selected was given, when planted out as a progeny lot, the prefix number of the year of single-plant selection, for example, in 1946: 6/–; the following number was the number of the single-plant lot retained for planting that year, for example, 6/320. 6/320 was grown as a progeny lot for the first time in season 1946–7.

The multi-line seed issues have the prefix UK (Ukiriguru), and the year of constitution; thus UK.51 was issued for planting in the 1951–2 season.

Characters measured, over and above yield and the hazard characters, were: ginning percentage (strain-trial yields are given as lb. lint per acre), lint index, lint length, and the percentage of damage to the seed coat after ginning, giving an assessment of the amount of seed coat nep to be found in the lint. These characters all vary with growing conditions and ginning treatment. The Shirley Institute (B.C.I.R.A., Manchester) assessments, of fibre characters and spinning qualities, have been invaluable in checking on any possible drop in lint quality. Now, a lint-quality-classifying assessment of material is made by the Tanganyika Lint and Seed Marketing Board. This assessment is greatly valued.

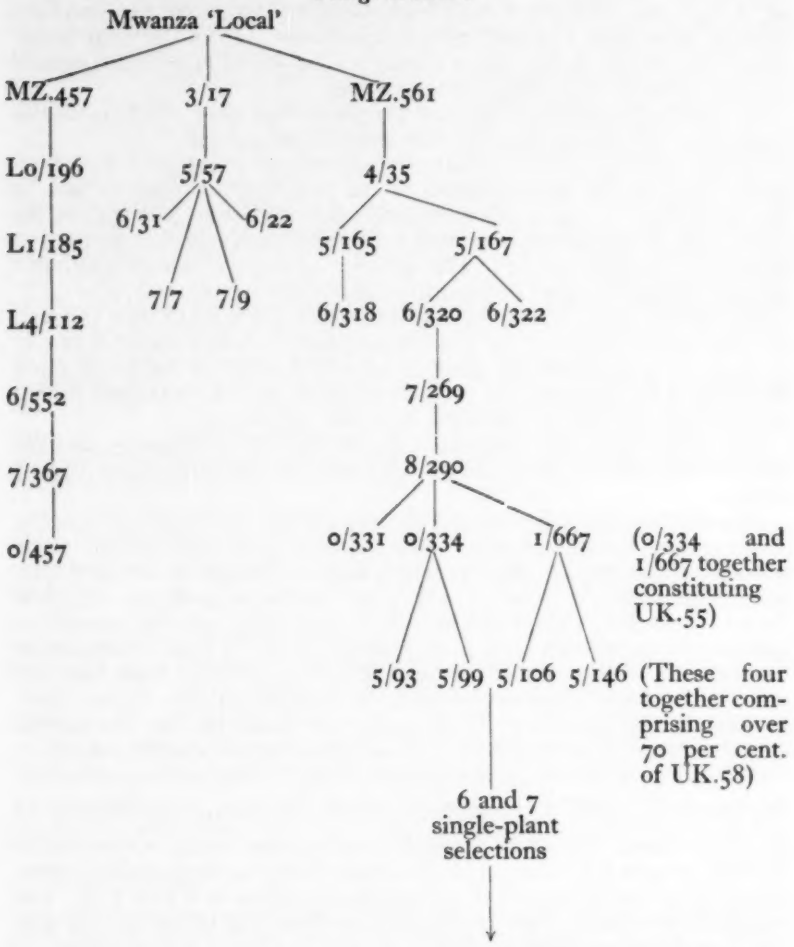
The Shirley Institute effective length of the Ukiriguru strains retained, lies around $\frac{38,\ 39,\ 40}{32}$ in., varying with different growing conditions. In practice, around the better Lake-shore areas, that means a commercial grading up to a full $1\frac{1}{8}$ in., with the staple dropping in the inland areas, especially in the latter part of the season, to as low as a bare 1 in. The standard fibre weights per centimetre run from just under to over 200. There are also variations in these.

In addition to the environmental factors affecting quality, as between the better Lake-shore areas and the inland areas, the broken nature of the country induces quality variations from year to year within quite a limited zone. As a generalization, the better grown the cotton, with good farming, the better the staple length and quality. Seasonal variations are also induced by the timing of mid-season drought periods.

Selection in Mwanza 'Local', MZ.561 and MZ.457

The course of the selections described in the following pages is summarized in the Pedigree Chart below.

Pedigree Chart



Among the thousands of selections made directly out of Mwanza 'Local', only one major parent stock, 3/17, selected in 1943, four seasons after the programme had started, was for a time a high 'possible', providing a range of interesting segregates. 3/17 itself featured in UK.46, the first of the multi-line issues; in UK.48 nearly one-half was of 3/17 origin; a first-generation-daughter strain, 5/57, was an important constituent of the issue; and derivatives of 5/57 were constituents of UK.51. But they and later derivatives have not maintained a leading lint-yield position compared to the 8/290 segregates; apart from featuring in the hybridizing programme they have now been relegated.

None of the material from MZ.457 continues. Selections from the Lubaga strain, L4/112, itself four generations from Mwanza 'Local', were worked with for a considerable number of years, but finally discarded. It was found that they possessed little or no resistance to bacterial blight, the seriousness of which varies from year to year.

The cream of the material has come from MZ.561. In 1944 a selection, 4/35, was made directly from it. From the 1945 field notes, the progeny lot was recorded as 'mixed', as a lot not good enough for jassid resistance, but fairly vigorous, leafy, and a good cropper. Four single-plant reselections for better leaf hair were made, but 4/35 as a progeny lot, amongst the hundreds of others handled in 1945, was discarded. Of the three single-plant reselections retained and grown in 1945–6 as progeny lots, two, 5/165 and 5/167, were kept on. The third was discarded for insufficient jassid resistance. It was not then appreciated what gold was in these lots. In the field records, neither 5/165 nor 5/167 was recorded as other than 'fair', and 5/167 of doubtful blackarm resistance. From reselections made in 1946, three strains, grown as progeny lots in 1946–7, were outstanding in that season, i.e. 6/318 ex 5/165; and 6/320 and 6/322 ex 5/167; four generations away from Mwanza 'Local'.

The 6/318 segregates were very attractive looking, heavy cropping, rather small bolled; but in the end they proved not to have in them a high enough degree of jassid resistance, nor, as it now turns out, any worth-while blackarm resistance. A great number of 6/318 daughter strains were tested before being relegated. It is interesting that at first, 6/318 segregates were preferred to the 6/320 and 6/322 segregates. 6/318 itself constituted 33 per cent. of the multi-line issue UK.48.

An outstanding selection was made in 1958, 8/290, out of 7/269, a daughter strain ex 6/320. In 1950 and 1951 secondary reselections were made from 8/290. The two best—seven generations away from Mwanza 'Local'—0/334 and 1/667, are now the premier Ukiriguru straight stocks (as distinct from oncoming hybrid material). They were issued jointly for multiplication as UK.55. Reselections from these, still showing segregation eight and nine generations away from Mwanza 'Local', are still under test; a number of the best were issued as UK.58. (It is interesting to record, as showing the segregation still occurring seven generations away from Mwanza 'Local', that 0/331, a sister strain of 0/334, showed insufficient general jassid resistance.)

From the strain 6/322, reselections were made until 1950, but these proved not to be of the same calibre as the 8/290 reselections.

In the material from the progeny lot 4/35, therefore, widely different plant types and characters have shown up. The vintage showing was in 1946–7, when 6/318, 6/320, and 6/322, as progenies, showed their outstanding qualities.

It is fully appreciated that, even after the programme had started, natural crossing could have played a part in at least early variability expression. At the first stage single plants taken in bulks would not have been selfed; but selfing was attempted on two or three lines of single-plant progeny lots. Where possible, selfed seed was used in lots being

carried forward, though some secondary reselections did come from the unselfed portions of lots. When families emerged, groups of associated strains, for example from 5/57, or 6/318, or 8/290, were planted together, so that such natural crossing as did occur would, with rare exceptions, be within the family, or much more likely with a neighbouring plant in the same plot. 'Exotic' material, i.e. other than of Mwanza 'Local' origin, with the exception of the early U.4 material, has always been grown apart from the main breeding plots.

The 8/290 strains are amongst those with the heaviest boll weights; the bolls open well, making for ease of picking. Seed weights are high; lint indices are also high, so therefore are ginning percentages. The 8/290 strains are slightly slower in starting substantial cropping compared to MZ.561 and some of the other strains; due, at least partly, to a higher node number to the first sympodial branch; but they are good middle croppers; they have an especially good capacity for making a top crop when conditions are favourable, when some of the earlier-setting strains have finished cropping.

(One very interesting point in the first-named author's experience is that habit, more especially in monopodial development, can be related to environment—altitude, and therefore probably temperatures. At an altitude of 3,000 to 4,000 feet there may be important monopodial branching, largely suppressed at under 1,000 feet.)

Resistance to Bacterial Blight

Arnold [8, 10] has shown that, while not possessing the degree of bacterial-blight stem resistance, and boll-rot resistance, of the best Albar 51 hybrids, UK.55 has reasonable stem resistance, and better resistance to bacterial boll rot, compared to 'Local', MZ.561, and the earlier issues. Thus resistance to bacterial blight played a part in selection, before more exact estimations of bacterial-blight resistance were possible. In all strain trials the end criterion has been yield of lint per acre, together with, of course, the quality characters desired. Susceptibility to bacterial blight would have lowered yields in bacterial-blight years. In field assessments of breeding lots, before the trial stage, there had been a discarding for 'scruffiness', which in the light of present knowledge undoubtedly was largely a discarding for bacterial-blight susceptibility.

A very good demonstration [11] of how yield can be reduced by bacterial-blight attack in a bacterial-blight year showed up in a fertilizer trial in 1956. Replications in this trial had been used for bulking strains. A strain with, as it proved, little or no resistance to bacterial blight, but otherwise very good, 0/457 ex a daughter strain of L.4/112, compared to 8/290 and an 8/290 segregate, gave reduced yields varying between 400 and 800 lb. seed cotton per acre, a reduction of over 30 to over 40 per cent.

Provincial Cotton Seed Issues

MZ.561 and MZ.457, each only one generation away from Mwanza 'Local', were first issued for multiplication in the 1939–40 season, after

some years of testing against Mwanza 'Local'. MZ.457 was withdrawn at the end of that season because of insufficient jassid resistance.

The first multi-line issue, with which the first-named author was concerned, was UK.46, constituted for first multiplication in the 1946–7 season. It consisted of seven strains; four Ukiriguru strains, i.e. one (3/17) directly out of Mwanza 'Local', one directly out of MZ.561, and two out of daughter strains of MZ.561; and three Lubaga strains of MZ.457 origin. These seven strains represented the best material available at that time, from strain trial tests at Ukiriguru and at Lubaga. Later, UK.46 proved not to have a high enough degree of jassid resistance, and it has now been shown to have poor bacterial-blight resistance.

UK.48 was constituted for first multiplication in the 1948–9 season. It consisted of the four best Ukiriguru strains then available; nearly one-half of UK.48 was of 3/17 origin, and one-third was 6/318. No Lubaga strain was good enough for inclusion. The general levels of yield, compared to MZ.561 and UK.46, are shown in Figs. 1 and 2 (see pp. 128 and 131). There are very big variations between seasons. UK.48 had a better level of jassid resistance than UK.46.

UK.51, at present the commercial stock in the Lake Province of Tanganyika, and grown in parts of Kenya, was first issued in the 1951–2 season. It consisted of the seven best Ukiriguru strains, tested on Ukiriguru, at Lubaga, and in the district plots. The general level of yield compared to MZ.561 and the earlier issues are shown in Figs. 1 and 2 and are compared to MZ.561 in Tables 1 and 2 (pp. 130 and 132). Nearly half of this issue was 8/290, and one-fifth was associated strains of 8/290, out of 6/320 and 6/322; one-fifth was of 5/57 origin—a daughter strain of 3/17.

A multi-line strain UK.53 was constituted and tested, but, not being an improvement on UK.51, was not continued.

On reviewing the material available for the UK.55 issue, from the strain-trial results the premier constituents had to be 0/334 and 1/667, both ex 8/290. There were disadvantages in including non-8/290 strains, because of the lower order of yield. Strains of 5/57 origin, though having good lint quality, over the years did not yield so well as the 8/290 segregates; and they had appreciably smaller seeds, making for complications in commercial ginning if included in an issue. After considerable thought, UK.55 departed from the previously accepted multi-line concept in consisting of only two closely related strains.

UK.58 was issued in 1958–9, consisting of daughter strains of 0/334 and 1/667, the top yielders in the scatter of strain trials, and all with lint, from Ukiriguru, commented upon favourably by the Tanganyika Lint and Seed Marketing Board.

There is no finality to successive seed wave issues. The best material available at the time of issue is used, to be succeeded in turn, as better segregates show up with further testing. (The combining ability of 'possible' strains for a multi-line issue has not yet been studied at Ukiriguru [12].) If the policy had been one final strain issue for a period, the years of testing before issue would have to be prolonged, and inadequate use would have been made of later-emerging better segregates.

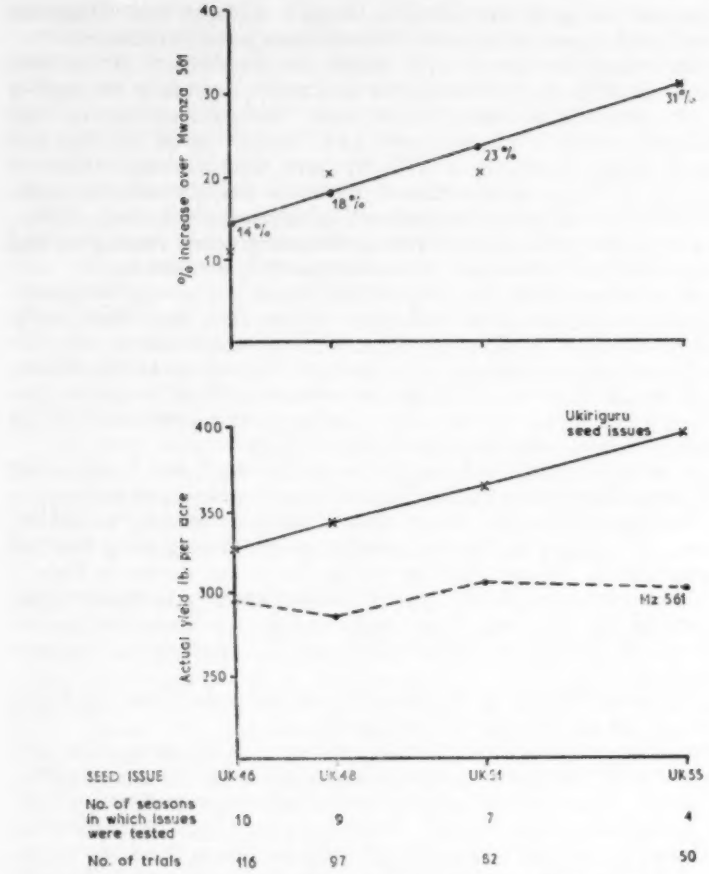


FIG. 1. Lint per acre increment of Ukiriguru seed issues over Mwanza 561 from strain trials 1947–8 to 1957–8

Yield Increases arising from the Breeding Programme

The production of cotton in the Lake Province of Tanganyika has increased from a 10-year average of 33,500 bales for the period 1935–44, to over 180,000 bales at the time of writing. The present target is 200,000 bales, of value about £8,000,000; this could be exceeded. The provincial mean yield of lint per 100 acres has increased from just under 20 to just over 40 bales. These yield increases have been partly due to increased planting in newer and richer areas. But the succession of seed issues, especially being resistant to jassid damage and later with some resistance to bacterial blight, in addition to increasing yield directly, has given confidence to expansion and has contributed to stability of

production. There has been a marked improvement in the market reputation of the crop—to a large extent a direct reflection of the improvement in the nourishment of the lint as a result of jassid resistance [7].

MZ.561 is now superficially indistinguishable from 'Local'. They both have a leisurely fruiting habit, but given freedom from jassid attack and other hazards, and a long growing season, they can on occasion yield much better than was at one time expected relative to the newer material. In the main trials at Ukiriguru (Table 1), MZ.561 lint yields range from 72 to 97 per cent. of the yield of UK.51. At Lubaga in some years, though under harder conditions, MZ.561 can yield as much as 92 per cent. of the UK.51 lint yields; in other seasons yields are only around 60 per cent. of the U.K.51 yield; in 1955 at Lubaga the profit from the newer material was spectacular. At Ragata (Ukerere Mainland) and Arugongo (Geita Lake Shore) district plots, with very good growing conditions, the lint yields of MZ.561 are mainly around 90 per cent. of UK.51. At Mwanangwa in the Kwimba district, 20 miles south of Ukiriguru, the general level of yield increases is good—both the yield increases of UK.51 compared to MZ.561, and the yield increases of 0/334 compared to UK.51. Table 2, to be discussed later, shows the substantial improvements at the inland district plots.

Summing eighty-two strain trials, at station and district plots, 1947–8 to 1957–8 (Fig. 1), in 'valid trials' over seven seasons UK.51 yielded a mean of 64 lb. lint per acre per year more than MZ.561, a mean increase of 21 per cent. It is the view of the first-named author that in fact the increased yields from jassid resistance and bacterial-blight resistance, compared to the susceptible MZ.561, might well be greater in general peasant growing than the comparative yields disclosed in small-scale formal statistical trials, because of the partial protection afforded in trials by resistant material, and because the great majority of the trials recorded were reasonably well-grown crops. The expressions of jassid and blackarm attack are heavier on more poorly grown crops.

UK.55, in fifty 'valid trials' over four seasons, has yielded a mean of 93 lb. of lint per acre per year more than MZ.561, a mean increase of 31 per cent. Could the Province yield at the level of these trials—the majority, incidentally, African-peasant cultivated in district plots, and including poor-land trials—the increase, at the present Provincial acreage, when UK.55 and UK.58 cover the Province, could represent a profit from these seed issues, compared to the continued cultivation of MZ.561, approaching 100,000 bales per year of value about £4,000,000. The potential for considerable economic advancement is there as a result of the breeding work. But because of the much lower average yields of the growers, say about 460 lb. seed cotton per acre (about 150 lb. of lint per acre), the profit to the Province in baleage increase would in fact be less than this figure.

In Table 1 and Fig. 2 the increased yields over UK.51 are shown for 0/334 (ex 8/290 and half component of UK.55), and the parent of some of the most promising straight strains now being tested. The increased yields of UK.55 over UK.51 are shown in Figs. 1 and 2 and in Table 2.

The 0/334 yield increases in Table 1, expressed as lb. lint per acre, vary considerably from season to season and from area to area, from no improvement, to an increase of 42 per cent., in the Ukiriguru main trial; and to an increase of 73 per cent. at Lubaga. In the district plots improvements up to 37 per cent. are recorded at Mwanangwa, and up to 28 and 24 per cent. for the two Lake-shore district plots, there representing increases of 158 and 120 lb. lint per acre.

TABLE 1. *Lint Yields*

(MZ.561 as Percentages of UK.51)

Year	*Ukiriguru Research Centre Main trial (Manured Hill sand)*	*Lubaga Sub-Station Shinganga District (Black loam)*	*Mwanangwa, Kwimba District plot (Black loam)*	*Ragata, Ukerewe Mainland District plot (Rich Hill sand)*	*Arugongo, Geita (Lake Shore) District plot (Fertile Lake-shore sand)*
1952	72*	61*	76*	..	81*
1953	85*	92	96	..	100
1954	83	56*	69*	94	90*
1955	78*	33*	81	82	89
1956	78*	68	65*	105	93
1957	97	87	72*	88*	90
1958	89	90	77*	96	91
Mean levels of yield, U.K.51. lb. lint per acre	500	267	*Over five seasons* 335	565	500
Percentage Increases in Lint Yield. 0/334 over UK.51					
1953	0	+6	+21*	..	−20 (8/290)
1954	+42*	+8*	+10	+8	+24*
1955	+12*	+73*	+37*	+6	0
1956	0	0	+15*	+5	+12
1957	+8	0	+31*	+11	+5
1958 (0/334 and 1/667 segregates)	+12	+5	+18*	+28*	+11

* Individual differences significant for the year of trial at $P = 0{\cdot}05$ level.

Good-land and Poor-land Trials

In a series of 'valid trials' in 1952 and in 1953, from thirty trials on good land the mean yield for UK.51 was 365 lb. lint per acre, and for MZ.561, 295 lb.—a mean increase of 70 lb. (24 per cent.). In thirteen trials where yields had not exceeded 500 lb. of seed cotton per acre—approximating more to the mean African cultivator level—UK.51 gave a mean of 155 lb. lint per acre, and MZ.561, 115 lb.—a mean increase of 40 lb., compared to the good-land increase of 70 lb. (but a percentage increase of 35 as compared to 24).

Comparing the 1958 Ukiriguru good-land and poor-land trial yields,

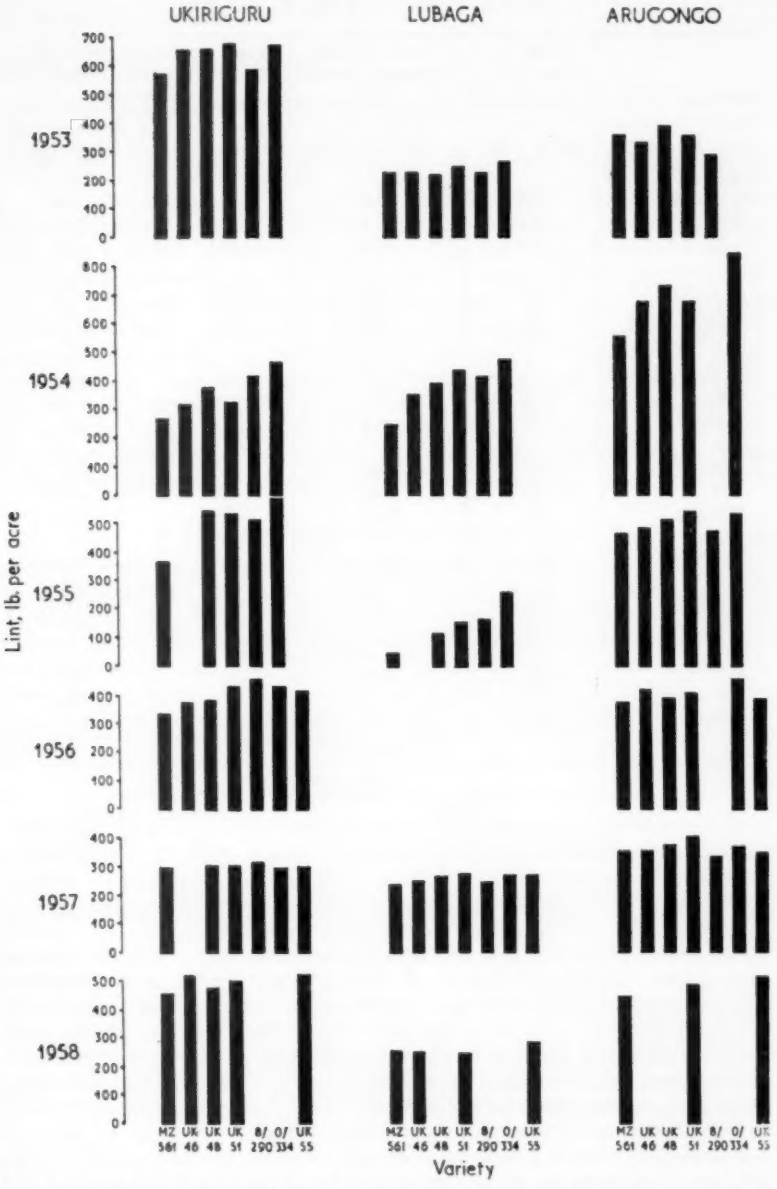


FIG. 2. Seasonal and site variations in yield of Ukiriguru seed issues and selections.

TABLE 2. *Yields of Lint, lb. per acre*

	From five Lake-shore district plots. Area A (Musome, Nassa, Ukerewe, and Geita)		*From six Inland district plots Area B (Kwimba, Maswa, and Shinyanga)*	
	Mean yield	*Percentage of MZ.561 yield*	*Mean yield*	*Percentage of MZ.561 yield*
1955				
MZ.561	396	100	252	100
UK.51	454	114	323	128
UK.55	472	119	384	152
1956				
MZ.561	279	100	237	100
UK.51	302	108	326	138
UK.55	283	102	365	154
1957				
MZ.561	306	100	237	100
UK.51	348	113	331	139
UK.55	377	123	382	161
1958				
MZ.561	348	100	312	100
UK.51	377	108	350	112
UK.55	401	115	380	122
1959				
MZ.561	382	100	244	100
UK.51	407	107	271	111
UK.55	437	114	292	120
UK.58	461	121	313	128
	5-year means			
MZ.561	342	100	256	100
UK.51	377	110	320	125
UK.55	394	115	361	141

	Main strain effects				
	Yields			*Increases over MZ.561*	
	MZ.561	*UK.51*	*UK.55*	*UK.51*	*UK.55*
Area A	342	377	394	+35	+52
Area B	256	320	361	+64	+105

UK.51, yielding at the rate of 1,450 lb. seed cotton per acre, was 10 per cent. better (44 lb. lint per acre) than MZ.561 in the main manured trial; 0/334 and 1/667 segregates were 22 per cent. better (100 lb. lint per acre) than MZ.561, or 11 per cent. better than UK.51. In the poor-land trial, UK.51, yielding at the rate of 809 lb. of seed cotton per acre, was 17 per cent. better (40 lb. of lint per acre) than MZ.561; the 0/334 and 1/667 segregates were 33 per cent. better (79 lb. of lint per acre) than MZ.561, or 14 per cent. better than UK.51.

There has been a greater percentage increase in the capacity of the improved material to yield under less favourable conditions, but the slightly higher actual lint-yield increases came from good growing

conditions. The seed issues thus cater reasonably for the poor cultivator as well as for the richer areas.

Lake Shore and Interior Trials

There has been discussion whether the differential strain responses obtained at Ukiriguru apply equally to the south of the Province, where the acreage planted to cotton is expanding, to a large extent on dark heavy soils and with a poorer rainfall. There the level of yields is generally lower and the lint quality poorer. The results set out in Table 2—including those from the 1958–9 season, and in this instance including UK.58—answer this query. The increases from the strain issues are considerably greater in the middle and south of Sukumaland than in the better-growing Lake-shore areas. In Table 2, over five seasons, the mean yields are compared from five Lake-shore district plots, and six middle and inland district plots. The strain effects, comparing UK.51 and UK.55 with MZ.561, are about double for the middle and inland district plots compared to the Lake-shore plots. (At Lubaga, in the 1959 season in the three trials there, yields were low; but UK.55 yielded 65, 78, and 55 per cent. better than MZ.561; and UK.58, 34, 92, and 46 per cent. better than MZ.561.)

Ukiriguru Stocks on the Kenya Coast

UK.51 seed was imported from the Lake Province, Tanganyika, as the seed stock for the Kenya coast. It has proved successful; at the Msabaha Cotton Station near Malindi more successful in 1958 than UK.55, and in the presence of an American bollworm attack, in 1959, more successful than UK.58. UK.55 and UK.58 are later in making a crop than UK.51. It is the summing of many influences which determines whether a strain, bred for a particular set of conditions, does or does not fit into a different environment.

Review

The yield increase differences from year to year and from area to area are associated without a doubt with the pattern of the season and the hazards. Arnold [8] has referred to the varying degrees of attack of bacterial blight influencing differential strain responses in different seasons. It is impossible to estimate ahead for any season what improvement is to be expected. A mean assessment, on which seed-issuing policy can be based, is all that can be given. The need for continuity of observation over a variety of seasons is obvious; preferably with a considerable continuity of staffing.

In reviewing the achievements of the breeding programme it is interesting to reflect, in giving thought to possible breeding systems, that if, by chance poor siting of the parental lot and consequent poor showing, it had not been thought worth while making the selection 5/167—competing for possible handling with the hundreds made that season—the outstanding Ukiriguru stocks would not now be available; secondly, that the cream of the present Ukiriguru material came from a

straight selection from MZ.561, i.e. 4/35, itself discarded after one season's growing as a progeny lot, from which only two single-plant progenies were continued, not in themselves recorded as other than 'fair'. By the same token it is probable that equally worth-while material may have been missed by premature discarding of mixed lots.

The moral seems to be to have as much primary selection as is possible for the characters desired, and then if at all possible to carry forward secondary reselections, even if mixed, for at least two seasons for further observation, unless obvious general faults are there, such as insufficient leaf hair, susceptibility to bacterial blight, lint faults, &c. The temptation to discard, to bring material to manageable proportions, is overwhelming —even in Africa with many, though not always particularly enlightened, hands.

However much working-over of earlier material had been done, in the absence of some important genes which must be present in 8/290, the present results would not have been achieved.

Had a bacterial-blight-resistance hybridizing programme not been a first priority, a hybridizing programme of UK strains, and possibly some introduced material, would have been undertaken to induce wider variability in the range of qualities desired—but without an understanding of the gene complexes involved.

Breeding Improvement

One important aspect of breeding improvement and successive wave issues of improved seed in an African peasant economy, is that improved yields are effected *without effort on the part of the cultivators*. Seed is distributed free by the Department of Agriculture. Agronomic improvement in the Lake Province of Tanganyika (the subject of separate papers) would raise production considerably, to the great benefit of the economy, but this would require effort on the part of the peasant cultivators, which effort up to the present they have not been willing to provide.

Present position. It would appear that blackarm (bacterial-blight stem attack) is kept reasonably in check by the growing of UK.55 and the subsequent issue, UK.58, combined with seed dressing [13, 14]. But in some areas in all seasons bacterial boll-rot can cause considerable loss. There is at present a testing of later 0/334 and 1/667 segregates, but more important, a testing against these of Arnold's boll-rot resistant segregates from the hybridizing programme, Albar 51 (from Namulonge, ex Northern Nigerian [7]) × various Ukiriguru strains. It would seem that, with the Ukiriguru facilities available, the range of types emerging from this programme could not have been foretold genetically. The best of the segregates are highly promising; but, especially because they are strains of hybrid origin, continued testing is necessary throughout the Province, in difficult as well as good seasons: differential responses occur in seasons of well-distributed rains, as compared to seasons with mid-season droughts, and seasons with an early finish to the rains.

There is by the second-named author an attempt at an understanding of cropping habit in the Lake Province environment—marked earliness in cropping compared to a more leisurely setting of the crop, and the

relationship of cropping habit to the different types of seasons, and times of planting.

Fusarium wilt is recorded in small areas on the Lake shore of the Geita District, west of Smith Sound. Though distressing to individual cultivators, as a hazard it is as yet economically unimportant. Genetic variability for resistance occurs in the UK material should it be considered desirable later to exploit such resistance.

Acknowledgements. The first-named author has been in charge of the work since the 1939–40 season. He was single-handed on Ukiriguru, with a large development programme, until the 1947–8 season. Facilities were limited until about 1951. Mr. A. N. Prentice was stationed at Lubaga, from late 1939 until 1947, and then at Ukiriguru until early 1949. Mr. J. M. Munro was at Ukiriguru from 1949 until late 1955. Mr. M. H. Arnold has been stationed at Ukiriguru since late 1952, and Mr. K. J. Brown since 1955. All have been associated with the breeding programme to a greater or lesser extent, over and above other commitments.

The authors, and the other officers associated, have been Empire Cotton Growing Corporation staff working on Tanganyika Department of Agriculture stations, at Ukiriguru, and to a much lesser extent at Lubaga. The programmes have been under successive Directors of Agriculture.

The first-named author acknowledges with appreciation the counsel, and the facilities made available, by Dr. E. W. Russell, Director, E.A.A.F.R.O.; for residence, the use of the Library, and generally the opportunities for reviewing and writing, at Muguga, near Nairobi, Kenya.

REFERENCES

1. S. C. Harland. *Empire Cotton Gr. Rev.*, 1955, **32**, 20.
2. J. E. Peat and A. N. Prentice. Prefix to *Prog. Rep. Exp. Stas.—Empire Cotton Gr. Corp., Lake Prov., Tanganyika*, 1945, p. 101.
3. —— —— *E. Afr. Agric. J.*, 1949, **15**, 48.
4. D. W. Malcolm, *Sukumaland*, Oxford University Press, Int. Afr. Inst., 1953.
5. W. V. Harris, *Dept. Agric., Tanganyika*, Pamph. No. 29, 1942.
6. J. D. Tothill, *Agriculture in Uganda*, Oxford Univ. Press, 1940, 183.
7. J. B. Hutchinson, *The Application of Genetics to Cotton Improvement*, Cambridge Univ. Press, 1959, pp. 39, 72, 74.
8. M. H. Arnold, *Resistance to Bacterial Blight* (Xanthomonas malvacearum) *in Lake Province 'Local' Cotton*, Proc. W. Afr. Cotton Res. Conf., 1957.
9. F. R. Parnell *et al.*, *Bull. Ent. Res.*, 1949, **39**, 539.
10. M. H. and K. M. Arnold, *Prog. Rep. Exp. Stas.—Empire Cotton Gr. Corp., Lake Prov., Tanganyika*, 1958, p. 13.
11. J. E. Peat and K. J. Brown, ibid., 1956, p. 11.
12. J. T. Walker, *Intra-varietal Heterosis and the Multi-line Concept*, E. Afr. Spec. Comm. Agric. Bot., Paper, Arusha Meeting, 1960.
13. M. H. and K. M. Arnold, *Prog. Rep. Exp. Stas.—Empire Cotton Gr. Corp., Lake Prov. Tanganyika*, 1957, p. 18; 1958, p. 16.
14. M. H. Arnold, *Empire Cotton Gr. Rev.*, 1959, **36**, 161.

(*Received 30 April 1960*)

RESIDUAL EFFECTS OF PHOSPHORUS FERTILIZERS IN KENYA

E. BOSWINKLE

(*Department of Agriculture, Nairobi, Kenya*)

Summary

Residual effects of phosphorus fertilizers were tested for from five to nine seasons in three experiments in Kenya, two at the lower altitudes on red lateritic soils derived from Archaean 'Basement Complex', and one at a higher altitude on a red soil derived from a tertiary phonolitic lava.

The results showed that residual effects can be very considerable and persistent under a diversity of Kenya conditions. They do not support the widespread belief that tropical soils fix phosphate strongly.

The residual effects of water-soluble phosphate, of the type which Gethin Jones had shown by chemical tests to be strongly fixed when applied to latosolic soils, were greater than those of very finely ground crystalline rock phosphate such as Uganda rock phosphate.

It has been generally believed that tropical soils fix phosphorus strongly and therefore show small or no residual effects. While this belief, so far as it applies to Kenya, was taken as confirmed by chemical studies by Gethin Jones [1], critical field evidence was lacking until Holme and Sherwood [2], in their report on the fertilizer requirements of the Kenya Highlands, recorded residual effects in the year following the year of application, in a few of their field trials. The Kenya Department of Agriculture [3] undertook several fertilizer trials at different research centres, in which marked residual effects were obtained. Russell [4] reported that experiments in East Africa showed that benefits of phosphorus fertilizers last for two to three years. In other parts of Africa, such effects were confirmed by Le Mare [5], in soil fertility trials in Tanganyika; and by Nye [6] in Ghana, though there the sandy soils under investigation had a low phosphorus-fixing capacity.

In an earlier paper, the author [7] reported that on a dark red soil derived from andesite, in the Kenya Highlands, residual effects, expressed in terms of yield, energy production, or gross profit, may be very considerable, though these are greatly dependent on the crop rotation. The results of other experiments in Kenya, at different altitudes and climatic conditions, on different soils and different crops, are discussed in this paper.

Experiment 1

This experiment was laid down in 1952 at Makaveti, south-east of Nairobi, at an altitude of 4,900 ft. and with an average annual rainfall 29·3 inches. Two rainy seasons are clearly distinguishable, the long (L.R.) and the short (S.R.) rains, with intervening hot and dry periods; two crops a year are usually obtained. Generally, the short rains are better distributed and better suited to seasonal cropping than the long

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

rains, and this was very noticeable in the results. The uncertainty of securing a crop of the local maize in the long rains is obvious.

The soil of the experimental site is derived from a metamorphic rock (biotitic gneiss) of the Archaean Basement Complex, and the profile (J. Thorp, private communication, 1958) is as follows: 0–6 in., dusky red to dark reddish-brown (2·5 YR 3/3 moist—Munsell colour notation) friable clay loam; 6–18 in., dark reddish-brown (2·5 YR 3/4) friable clay; 18–32 in., dark reddish-brown to dark red (2·5 YR 3/5) friable clay; below 32 in., stone layer with clay in between quartz pebbles.

The soil analysis by Mehlich's extraction method (0·1N HCl:0·025N H_2SO_4 mixture) [8] is shown in Table 1:

TABLE 1. *Analysis of Soil of Experiment 1 (Makaveti)*

pH	P (*p.p.m.*)	*Exchangeable bases (m. eq. %)*				
		Ca	Mg	Mn	K	Na
5·2	8	4·8	3·3	0·4	0·8	0·2

These figures are typical for most red sandy soils of the Basement System: acid reaction; low exchangeable bases and phosphorus.

In this experiment, two replications of a 3^3 factorial design were employed, the highest-order interaction being partially confounded with blocks. Plot size was 1/34 acre. The two replicates were situated on level ground, and the top soil was in a fair structural condition though there were some signs of past erosion. The land had not previously received fertilizers or manures.

The treatments were as follows: double superphosphate (39–41 per cent. water-soluble P_2O_5) and ammonium sulphate (20·8 per cent. N), each at 0, 1, and 2 cwt. per acre (P_0, P_1, and P_2; and N_0, N_1, and N_2), and muriate of potash (60 per cent. K_2O) at 0, ½, and 1 cwt. per acre (K_0, K_1, K_2).

In the long rains of 1952 the above treatments were broadcast to maize at planting time, but yields were not recorded. In the following short rains of the same year, all treatments were reapplied but this time P and K were placed with the seed at planting time, and N was applied in bands near the rows as a top dressing. The total fertilizer applications in 1952 were thus 0, 2, and 4 cwt. per acre for N and for P, and 0, 1, and 2 cwt. for K. After these applications in 1952, only N and K were applied in subsequent years, generally in the long rains.

Results

The results are given in Table 2. The degree of replication and standard of experimentation proved fairly satisfactory: the coefficient of variation was on the average about 16 per cent. when climatic conditions were favourable for crop growth. No appreciable responses were obtained to either N or K throughout, nor were there any significant interactions NP or PK. Accordingly, yield data for these treatments have been omitted from the table and the discussion. Owing to a low

rainfall, no grain was obtained in three seasons, in which only stover weights were recorded.

The residual effects of P are marked, but after about four 'residual' seasons, those of the lower rate of phosphorus appear to have become insignificant.

TABLE 2. *Experiment 1 (Makaveti). Yields (lb. grain per acre)*

Year	Season	Rainfall (in.)	'Residual' season	Crop	'Double' superphosphate			Response (% of P_0)		Least sig. diff.	
					P_0	P_1	P_2	P_1	P_2	$P =$ 0·05	$P =$ 0·01
1952	L.R.	10·91	..	maize	..	..	..	..	..	..	..
	S.R.	9·23	..	millet	361	830†	1,002†	130	178	196	266
1953	L.R.	3·80	1	maize[a]	154	291	400•	89	160	226	312
	S.R.	15·09	2	beans	675	817•	898†	21	33	134	182
1954	L.R.	10·56	3	maize	1,715	2,238†	2,414†	30	41	256	348
	S.R.	14·43	4	millet	367	472†	524†	29	43	55	75
1955	L.R.	3·15	5	maize[a]	818	818	987	0	21	332	451
	S.R.	22·36	6	millet	1,114	1,210	1,285†	9	15	126	171
1956	L.R.	1·08	7	maize[a]	538	588	651	9	21	242	329
	S.R.	19·30	8	millet	702	777	814•	11	16	86	116
1957	L.R.	14·69	9	beans	700	737	810•	5	16	84	114

[a] Stover weight. • Sig. at $P = 0·05$. † Sig. at $P = 0·01$.

Experiment 2

This experiment was laid down at Kampi ya Mawe (altitude 3,700 ft., average annual rainfall 28·76 in.) in 1955; it was similar to the first in design, soil, and parent rock, except that no stone layer was apparent to a depth of 55 inches. The chemical analysis data were as follows:

TABLE 3. *Analysis of Soil of Experiment 2 (Kampi ya Mawe)*

pH	P (p.p.m.)	Exchangeable bases (m. eq. %)				
		Ca	Mg	Mn	K	Na
5·5	13	5·8	3·4	0·5	1·9	0·1

In this experiment 0, 1, and 2 cwt. of double superphosphate per acre were applied in the short rains of 1955 and their residual effects have been measured with no reapplication over the succeeding six seasons. The N and K treatments have been reapplied as in Experiment 1 but again have shown no effects and are therefore omitted from the table and the discussion.

Results

Table 4 presents the results. After six 'residual' seasons, both rates of application of double superphosphate continued to show significant residual effects. Also here there is an indication that for residual effects to show up, good growing conditions (mainly a satisfactory distribution

of the rainfall) should prevail. Unreliability of the long rains and the repeated failures of the long-rains crop at Kampi ya Mawe, as well as at Makaveti, are notable.

TABLE 4. *Experiment 2 (Kampi ya Mawe). Yields (lb. grain per acre)*

Year	Season	Rainfall (in.)	'Residual' season	Crop	'Double' superphosphate			Response (% of P_0)		Least sig. diff.	
					P_0	P_1	P_2	P_1	P_2	$P = 0.05$	$P = 0.01$
1955	S.R.	18·47	..	millet	846	1,312†	1,385†	55	64	172	234
1956	L.R.	2·30	1	millet	failure						
	S.R.	29·32	2	sorghum	2,500	2,428	3,047*	−3	22	409	556
1957	L.R.	12·04	3	millet	failure						
	S.R.	16·07	4	millet	535	581	651†	9	22	61	83
1958	L.R.	9·41	5	maize	711	754	791	6	11	165	224
	S.R.	12·96	6	maize	2,105	2,438*	2,476*	16	18	302	411

* Sig. at $P = 0.05$. † Sig. at $P = 0.01$.

Experiment 3

This experiment was under completely different soil, altitude, rainfall, and climatic conditions. It was sited on the Eldoret Experimental Farm, at an altitude of 7,000 ft. and average annual rainfall of 40·87 inches.

The soil, derived from the alkaline phonolite (Tertiary lava), is as follows: 0–6 in., dark reddish-brown (2·5 YR 3/4) clay loam; 6–26 in., dark red (2·5 YR 3/6) clay loam with iron and manganese concretions; 26–36 in., dark red (2·5 YR 3/6) clay loam with more concretions; below 36 in., very hard murram (laterite). This profile is typical of a large area around Eldoret. Owing to its shallow nature yields are low, and the effects of an unfavourable rainfall distribution are accentuated. Because of the altitude, crops from the temperate zone are cultivated, and the normal rotation is based on a sunflower–maize–wheat, –barley– or oats–ley sequence. There is only one rainy season but this is much longer and much wetter than the seasons at the sites of the first two experiments.

The soil analysis showed the following results:

TABLE 5. *Analysis of Soil of Experiment 3 (Eldoret)*

pH	P (p.p.m.)	Exchangeable bases (m. eq. %)				
		Ca	Mg	Mn	K	Na
5·0	2	3·6	1·2	0·6	0·8	0·3

This experiment sought to compare the direct, residual, and cumulative effects of an insoluble local rock phosphate, with an imported water-soluble, and with a locally manufactured citric-soluble phosphorus fertilizer. Wheat was the test crop during its complete cycle from 1952–7. The site was opened up from virgin land.

TABLE 6. *Yields of Wheat (lb. grain per acre)*

Year	Annual rainfall (in.)	Control (no P)	Uganda rock phosphate. Years of application			'Double' superphosphate. Years of application			Least significant difference		
			1st	1st & 2nd	1st, 2nd, & 3rd	1st	1st & 2nd	1st, 2nd, & 3rd	$P = 0.05$	$P = 0.01$	$P = 0.001$
1952	35·18	810	957	..	..	1,262	..	..	68	90	117
1953 'Residual' season	25·80	52	94 (1)	54	..	154 (1)	243	..	53	71	92
1954 'Residual' season	34·54	570	841 (2)	911 (1)	944	909 (2)	1,091 (1)	1,268	92	122	159
Mean 1952–4	31·84	477	619‡	666‡	639‡	753‡	877‡	933‡	53	70	91
1955 'Residual' season	39·98	104	169 (3)	215 (2)	298 (1)	219 (3)	319 (2)	377 (1)	37	49	64
1956 'Residual' season	46·93	200	295 (4)	348 (3)	385 (2)	272 (4)	406 (3)	430 (2)	66	87	113
1957 'Residual' season	28·18	288	439 (5)	516 (4)	586 (3)	388 (5)	633 (4)	626 (3)	133	177	230
Mean 1955–7	38·36	197	301†	360‡	423‡	293•	453‡	478‡	84	111	144
General Mean	35·10	337	460‡	513‡	531‡	523‡	665‡	705‡	36	49	63

• Sig. at $P = 0.05$. † Sig. at $P = 0.01$. ‡ Sig. at $P = 0.001$.

The numbers in parentheses, opposite 'Residual' season, refer to the number of years since that in which the fertilizer was last applied.

The design was a 10 × 10 latin square (plot size 1/52 acre) and the following kinds and basic rates of fertilizers were used: control (no phosphorus); Uganda rock phosphate (total P_2O_5 20–27 per cent.) at 816 lb. per acre; soda phosphate, a local phosphate manufactured by fusion of Uganda rock phosphate and Magadi soda (18–20 per cent. citric-soluble P_2O_5), at 466 lb. per acre; and 'double' superphosphate (39–41 per cent. water-soluble P_2O_5) at 200 lb. per acre; all placed in the seed-bed at planting time. In some treatments, the three fertilizers were applied only in 1952. In others, they were applied in 1952 and again in 1953; and in yet others they were applied in 1952, and again in both 1953 and 1954. From 1955 until 1958 there was no reapplication of phosphorus and only the residual effects were recorded. The basic rates were suggested by Doughty as a result of his experience with fertilizer trials in western Kenya [9].

Results

Table 6 presents the results except for soda phosphate, the effects of which differed from those of superphosphate only in being somewhat smaller but slightly more persistent.

In all years, and for all treatments (except Uganda rock phosphate in 1953), the fertilizer-treated plots significantly outyielded the controls.

The yields in the 1952–4 period show that all fertilizer treatments yielded significantly ($P = 0{\cdot}01$) more than the control, and the three successive applications of 'double' superphosphate were significantly ($P = 0{\cdot}01$) higher yielding than the three successive Uganda rock phosphate applications. Furthermore, the repeated applications of Uganda rock phosphate did not lead to yield increases significantly ($P = 0{\cdot}01$) higher than the single application, whereas with 'double' superphosphate the two and the three successive applications were significantly ($P = 0{\cdot}01$) better than the single application, and the three applications were significantly better ($P = 0{\cdot}05$) than the two applications.

Even though about two and a half times as much P_2O_5 had been added in the Uganda rock phosphate treatments as in the corresponding 'double' superphosphate treatments, the residual effects are strongly in favour of the latter fertilizer. The residual effects in 1956 and 1957 of the single application of 'double' superphosphate in 1952 admittedly have fallen to a level below that of the single application of Uganda rock phosphate, but these differences are not significant.

Acknowledgements. These experiments were carried out jointly by the officers of the soil chemistry section of the Department of Agriculture and the officers of the experimental stations, and the author wishes to express his appreciation to all these officers for the high standard of experimentation.

REFERENCES

1. G. H. G. Jones, *Dept. of Agric., Kenya Colony, Annual Reports, 1932–1938*, Nairobi, Govt. Printer.
2. R. V. Holme and E. G. P. Sherwood, *Colonial Research Studies*, No. **12**, London, H.M.S.O., Col. Office, 1954.

3. ANON., *Dept. of Agric., Kenya Colony, Annual Reports, 1954 and 1955*, Volume II, Nairobi, Govt. Printer.
4. E. W. RUSSELL, *Col. Office Paper No. 5*, London, H.M.S.O., Misc. No. 531, 1958.
5. P. H. LE MARE, *Empire J. Expt. Agric.*, 1959, **27**, 197.
6. P. H. NYE, ibid., 1954, **22**, 101.
7. E. BOSWINKLE, *E. Afr. Agric. J.*, 1960 (in press).
8. A. MEHLICH *et al.*, *Mass Analysis Methods for Soil Fertility Evaluation*, Nairobi. Department of Agriculture (in press).
9. L. R. DOUGHTY, *E. Afr. Agric. J.*, 1953, **19**, 30.

(*Received 16 May 1960*)

THE SIGNIFICANCE OF SEED-SIZE IN CULTIVATED TEA (*CAMELLIA SINENSIS* L.)

D. N. BARUA

(*Tocklai Experimental Staton, Indian Tea Association, Cinnamara, Assam*)

Summary

Size of the tea seed is a characteristic of the mother tree; the pollen parent seems to have little, if any, effect on seed-size. Manuring of a tea seed orchard with N and NPK reduced the number of small seeds. The pattern of size-distribution of seeds varies from one orchard to another, some orchards producing a higher proportion of small seeds than others.

Seed-size is related to the size of the resulting seedling. Seedlings raised from small seeds start with initial disadvantage, which justifies rejection of very small seeds. The smallness, however, should be adjudged with reference to most frequently occurring seed-size in an orchard. Seeds of the modal size grade tend to give the highest percentage germination. The practice of using a common, arbitrarily chosen, mesh for sieving out small seeds is discouraged as it may cause unnecessary loss of good seeds.

ALMOST all tea plants used in northern India for replacement of uneconomic populations, infilling of vacancies, and extensions, are raised from seed. The seeds are produced in orchards, varying in size from 2 to 3 acres to a few hundred acres.

In northern India, anthesis of tea flowers begins in November and lasts until January, with the peak in December. The fruit, which is a capsule, dehisces on the tree from October until December, and the fallen seeds are collected from the ground usually once a day. The major crop of seed is harvested in November.

After collection, the seeds are passed through a rotary-type shifter with a mesh size of half an inch. The seeds which pass through are discarded and the remainder are soaked in water for a few hours. Those which sink are then examined visually for removing bad and cracked seeds. The remaining good seeds are packed immediately for dispatch or stored for a few days in moist sand or subsoil.

In view of large-scale replanting of wide areas of tea in north-east India, the demand for good seeds has exceeded supply and many tea estates are now planting small orchards for their own future needs. Meanwhile, large quantities of seeds below the required size are discarded every year, as buyers prefer only the large seeds. This situation necessitated an inquiry into the significance of seed-size and the factors responsible for the production of small seeds. This paper records the results of such an inquiry.

Materials

Samples of seeds from a large number of orchards scattered over the plains of north-east India were examined. In one commercial orchard (Tocklai Stock number 112), seeds from each of the 686 trees in a block were collected separately.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

In addition, seeds from four biclonal matings and two experimental polycross orchards, Kailas and Gaurisankar, were also examined. Each polycross orchard, consisting of eighty-one vegetatively propagated plants from nine different clones, was planted in a 9×9 Latin square in a forest clearing. The plants were spaced 18 feet apart. Under this arrangement, each seed-tree was the centre of a group of eight trees belonging to eight different clones. The positions of the surrounding trees, in relation to the one at the centre, varied at random in each repeat. Seeds from each tree were collected, counted, and graded as described below.

Method

The tea seed is a spheroid, slightly flattened on the side of the hilum. Usually one, sometimes two, and rarely more than two seeds occur in

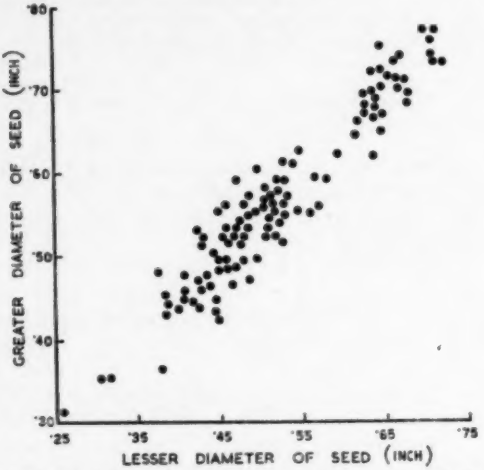


FIG. 1. Relationship between the lesser diameter through the hilum and the maximum diameter at right angles to the former, for a random sample of 110 spherically shaped tea seeds. Measurements taken with slide calipers.

the same loculus. When more than one seed develop in the same loculus, they become flattened on the sides which come into contact. Measurement with slide calipers showed that in seeds of all sizes the greater diameter is a linear function of the lesser diameter (Fig. 1).

The above relationship shows that the size of tea seeds can be determined from the lesser diameter. Hence the seeds can be arrayed into convenient size groups by passing them through slits of different width. In the present investigation, seeds were passed through slits of width 0·44, 0·52, 0·62, and 0·68 in., and thus separated into five size grades. The smallest seeds were designated grade I, the next group was grade II, and so on. Those held back by the biggest slit were put in grade V.

All seeds from each source were usually mixed after grading, and sown

in nurseries, but in a few instances, for observing the effect of size on germination and the subsequent growth of seedlings, seeds from each grade were planted separately.

Results

Sources of Variation in Seed-size

Between varieties. For the purpose of the present studies, progeny populations of different orchards were assigned to one or other of five groups. Those which as entities approximated more or less to the wild form of var. *assamica* were designated 'A' in Table 1; those which similarly approximated to the type variety (var. *sinensis*) were designated 'E'.

TABLE 1. *Seed-size of Progeny Groups ranging from Wild Form of var.* assamica *'A' through Various Intergrades to var.* sinensis *'E'*

Progeny group	*Number of progenies examined*	*Frequency per cent. of seeds in size grade*				
		V (largest)	*IV*	*III*	*II*	*I (smallest)*
A	7	8·3	26·5	47·8	12·2	5·2
B	70	17·1	27·5	43·1	9·4	2·8
C	20	11·6	26·6	47·4	10·9	3·4
D	2	2·6	15·3	72·9	7·8	1·4
E	1	0·4	3·8	43·5	30·4	21·9

TABLE 2. *Seed-size of Different Orchards within the Progeny Groups A, B, C, and D*

Progeny group	*Index number of orchard*	*Frequency per cent. of seeds in size grade*				
		V (largest)	*IV*	*III*	*II*	*I (smallest)*
A	32	27·2	37·0	33·8	2·0	0
	3	9·3	29·2	46·7	10·7	4·0
B	2	53·6	41·9	4·5	0	0
	14	1·7	18·6	50·1	22·3	7·3
C	47	3·9	50·6	43·1	2·4	0
	79	1·7	21·4	56·9	14·4	5·7
D	61	4·5	17·2	72·5	4·1	1·7
	82	0·7	13·4	73·2	11·5	1·2

The three other groups were designated 'B', 'C', and 'D', in order of overall intermediacy between the two varieties. The percentage frequency of seeds of different size grades for the five groups of orchards so defined is shown in Table 1.

Chi-square tests do not show any difference in seed-size between groups A, B, and C, but seeds of groups D and E are significantly smaller than those of the former three groups. Seeds of group E are the smallest, being significantly smaller than those of group D. The progeny populations of all the three groups A, B, and C are nominally referable to var. *assamica* and those of groups D and E to var. *sinensis*.

Between orchards. No generalization is possible from the foregoing data, however, as very few orchards were examined in groups D and E. Furthermore, examples given in Table 2 show that orchards within a group exhibit great variation in seed-size. Orchards 14 and 79 in B and C groups had significantly smaller seeds than orchard 61 in group D.

Between seed trees. Examples given in Table 3 illustrate that different trees within an orchard can bear seeds of very different sizes. Out of 686 trees examined in orchard No. 112, seeds borne by tree J 14 with the mode at grade V were the biggest, while those borne by tree O 7 with the mode at grade I were the smallest.

TABLE 3. *Seed-size of Trees within Orchard No. 112*

Index number of seed-bearing trees within the orchard	*Frequency per cent. of seeds in size grade*					*Modal size grade*
	V (largest)	*IV*	*III*	*II*	*I (smallest)*	
J 14	84·2	15·3	0·5	0	0	V
G 35	13·7	70·7	15·6	0	0	IV
K 35	0·5	6·0	77·5	16·0	0	III
M 33	0·5	0·5	24·5	54·4	19·1	II
O 7	0	0·8	15·3	37·1	46·8	I

Some Factors Affecting Seed-size

Genetical. The tea plant is largely cross-fertilized. The influence of the female parent on seed-size is demonstrated with the aid of the frequency histograms in Fig. 2. Each histogram of Fig. 2 represents a clone of the polycross orchard Kailas. Any chance bias in favour of one or more pollinators was neutralized by averaging data from all the nine repeats of the trial (see p. 144). The histograms indicate a strong maternal influence on the size of seeds. Statistical confirmation of this will be provided by Table 5.

In earlier experiments pollen from more than one source applied to the same female failed to show any definite effect of the male parent on the size of the resulting seeds. This observation is in agreement with that of Leliveld [1] on coffee, where bean size was determined by the mother plant and not by the pollen parent.

Seasonal. Extensive data on the seasonal variation of seed-size is lacking, but observations on the polycross orchard Gaurisankar over two seasons did not reveal significant difference between the seasons (Table 4). The data in Table 4, however, support the general experience of seed growers that the output of seed from an orchard fluctuates over a wide range from one season to another.

Manurial. The effect of inorganic manures on the size of seed was tested in the polycross orchard Gaurisankar. There were three manurial treatments: (1) N applied at 450 gm. per tree as ammonium sulphate; (2) NPK applied at 450 gm. N as ammonium sulphate, 900 gm. P_2O_5 as superphosphate, and 1,350 gm. K_2O as potassium sulphate, per tree; and (3) no manure. The fertilizers were applied in late March to 6-year-old trees. Analysis of variance of the data is given in Table 5, and the

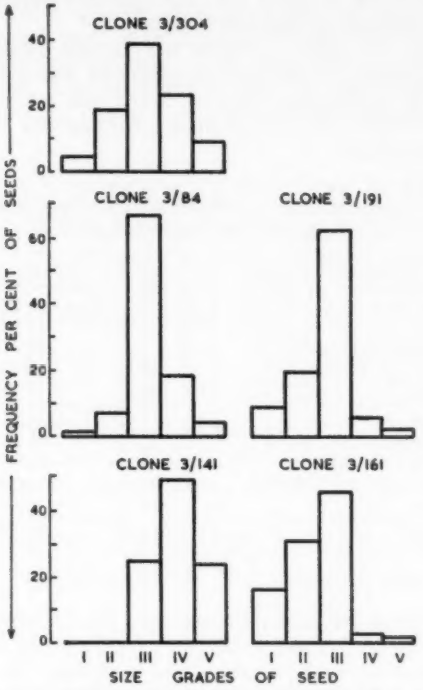


FIG. 2. Clonal variation in the frequency of seeds occurring in different size grades. Clones from the polycross orchard Kailas; seed yield for the year 1947.

TABLE 4. *Seed-size of the Polycross Orchard Gaurisankar for the years 1947 and 1948*

Size grade of seeds	*Frequency of seeds*	
	1947	*1948*
V (largest)	1,251	1,019
	1·70	*2·16*
IV	5,490	2,931
	7·46	*5·67*
III	44,055	25,527
	59·88	*49·37*
II	15,210	17,946
	20·68	*34·71*
I (smallest)	7,566	4,179
	10·28	*8·08*
Total	73,572	51,602

Figures in italics represent per cent. frequency.

frequency distribution of seeds into the five size grades for each of the three manurial treatments appears in Table 6.

The upper half of Table 5 shows that clones differ widely in their seed-yielding capacity. The effect of manures was just significant, but the absence of an interaction between clone and manure indicates that these inorganic fertilizers did not have a differential effect on the seed yield of different clones.

TABLE 5. *Analysis of Variance of the Absolute Number of Seeds of Polycross Orchard Gaurisankar, manured with* N *and* NPK

Source of variance	*D.F.*	*Mean square*
Block	2	238,548
Clone	8	378,612‡
Manurial treatment	2	290,284*
Clone × Manure	16	89,732
Error	52	75,490
Grade	4	1,455,651‡
Grade × Clone	32	161,710‡
Grade × Manure	8	151,749‡
Grade × Clone × Manure	64	42,732*
Error	216	24,111
Total	404	

* and ‡ indicate significance at $P = 0{\cdot}05$ and $0{\cdot}001$ levels respectively.

The lower half of the table shows that the difference between the number of seeds in the five size grades is highly significant. The grade × clone interaction also reached a very high level of significance, confirming the maternal effect illustrated by the histograms in Fig. 2. The significant grade × manure interaction, illustrated by the data in Table 6, shows that manures increased the size of seeds. This increase was observed in a young orchard on virgin forest soil, which indicates that the response of old orchards on comparatively poorer soils could have been even more pronounced.

TABLE 6. *Seed-size of Manured and Control Trees of Orchard Gaurisankar. Frequency per cent. of Seeds in Different Size Grades*

Size grade of seeds	*Manurial Treatment*		
	N	NPK	*No manure*
V (largest)	12·7	8·3	1·7
IV	17·1	18·2	7·4
III	49·4	55·6	59·9
II	14·4	12·5	20·7
I (smallest)	6·4	5·4	10·3

Significance of Seed-size

Seed-size and plant-size. Representative samples of seed of each of the five size grades were collected from the polycross orchard Kailas and

sown in two 5 × 5 Latin squares. The seeds were spaced 9 in. apart. The resulting seedlings of one Latin square were harvested at the ground-level after 8 months and weighed. The seedlings of the duplicate latin square were similarly harvested and weighed at the end of 2 years from planting. The results of the two experiments are presented in Tables 7 and 8.

TABLE 7. *Analysis of Variance of Fresh Weight per Seedling, raised from Seeds of the Five Different Size Grades*

Source of variance	*D.F.*	*Mean square*	
		8 months after sowing	*2 years after sowing*
Row	4	15·624	1,018·751
Column	4	12·840	105·984
Treatment (seed-size)	4	26·418‡	1,662·028†
Linearity	*1*	*88·978**	*4,033·816*
Deviation from linearity	*3*	*5·565*	*871·432*
Error	12	2·592	275·281

*, †, and ‡ indicate significance at $P = 0{\cdot}05$, 0·01, and 0·001 levels respectively.

TABLE 8. *Fresh Weight per See ling in gm. Seeds from Polycross Orchard Kailas*

Size grade of seeds	*Age of seedling*	
	8 months	*2 years*
V (largest)	9·06	119·34
IV	7·47	87·80
III	8·33	98·38
II	5·17	71·08
I (smallest)	3·54	82·79
L.S.D. at $P = 0{\cdot}05$	2·22	22·87

In each trial, seed-size had a significant effect on the size of the resulting seedling; the bigger seeds produced heavier seedlings. Similar results were reported by Tubbs [2] on tea and Gregor [3] on *Plantago maritima*. The 8-month-old seedlings showed a significant linear regression on the size of seeds, while the 2-year-olds did not. Furthermore, the difference between the biggest and the smallest seedlings was reduced by leaving them in the nursery for 2 years. The result, therefore, tends to indicate that the initial advantage of the big seed is minimized as the seedling grows.

In another experiment seeds from each of the 686 trees of orchard No. 112 were collected, graded, and sown separately in small nurseries. Each seed tree was given a grade number corresponding to the size of the most frequently occurring seeds on the tree. This is the modal size grade. The seedlings were pruned at a height of 20 in. from the ground after they had been in the nursery for 18 months and the fresh weight of prunings of each nursery was recorded separately. The weight of the

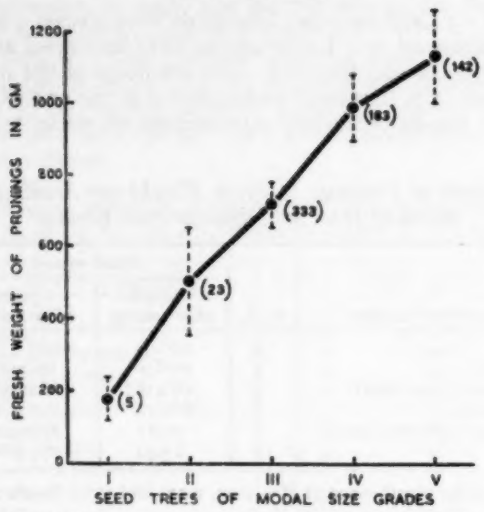


FIG. 3. Seed-size and mean weight of prunings of seedlings after 18 months. Figures in parenthesis indicate the number of trees in each size grade and the broken lines represent standard error of the means. Seeds collected in 1947 from orchard No. 112.

TABLE 9. *Frequency Occurrences, and Germination, of Seeds of Different Size Grades. Seeds from Polycross Orchard Kailas*

Size grade of seeds	*Frequency of seeds per cent.*	*Per cent. germination*
V (largest) . .	15·4	69·8±2·1
IV	30·6	67·3±1·6
III	44·1	71·4±1·3
II	7·8	43·1±1·8
I (smallest) . .	2·1	18·7±1·3

TABLE 10. *Percentage Germination, and Frequency per cent., of Seeds in Different Size Grades. Per cent. Frequency Figures are given in italics. Data from Four Artificial Bi-clonal Matings*

	Size grade				
Mating	*V (largest)*	*IV*	*III*	*II*	*I (smallest)*
Deopathar G×K	61·3	68·5	63·3	47·5	53·8
	17·4	*26·1*	*38·1*	*13·9*	*4·5*
3/107×3/22	66·7	50·0	68·8	66·7	0
	1·9	*15·0*	*77·5*	*5·6*	0
19/29/13/×19/35/2	0	66·7	81·8	75·3	73·7
	0	*2·8*	*66·9*	*18·6*	*11·7*
14/12/16×14/5/35	0	0	80·4	78·2	76·1
	0	0	*60·8*	*30·4*	*8·1*

prunings of 100 seedlings from each nursery is plotted against the modal size grade of the trees in Fig. 3. If the pruning weights are taken as a measure of the top-growth of seedlings, then the figure leads to the conclusion that the seed trees yielding a higher proportion of smaller seeds produce, on the average, smaller seedlings than those yielding a higher proportion of larger seeds.

The foregoing experiments warrant the conclusion that the size of the young tea seedling is determined by the size of the seed.

Seed-size and germination. Germination records were kept for the two 5×5 latin square experiments described in the foregoing section. The small seeds from this large-seeded orchard had poor germination. These results are presented in Table 9. The data, however, do not permit the generalization that small seeds from any source will have poor germinability. Amongst seeds from any source, poor germination may be associated with seeds of those size grades which occur infrequently. Table 10 lends support to this view.

Discussion

The size of tea seed is a characteristic of the mother tree. Orchards consisting of hundreds of trees appear to maintain a distinctive pattern of distribution of seeds into various size grades, from which it is often possible to distinguish one orchard from another. This difference between orchards is presumably caused by a variation in the proportion of large- and small-seeded trees.

While lack of or improper manuring of orchards can increase the proportion of small seeds (Table 6), yet data in Fig. 2 and Tables 3 and 5 clearly show that nutrition did not have appreciable effect on the genetical difference between trees bearing large and small seeds. Salisbury [4] also concluded that the effect of environment on fruiting individuals is to alter the number of seeds produced, but normally has little, if any, effect on seed-size. It therefore follows that the large- and small-seeded orchards differ in their genetic constitution and it will be wrong to expect a high proportion of large seeds from an orchard which is intrinsically small-seeded and vice versa.

Very small seeds produce seedlings which are notably small. In these experiments, the difference between seedlings raised from small and big seeds persisted for 2 years, even when the seedlings remained closely spaced in the nursery beds. Under these conditions the bigger seedlings must have suffered more from root competition than the smaller seedlings. If spaced out properly, then the bigger seedlings, by virtue of their better initial start, can be expected to maintain their superiority over small seedlings for a long time, although eventually the difference may cease to be noticeable. Thus there is some justification for sieving out and rejecting small seeds, but because a modal seed size is one of the characteristic features of a progeny, it seems logical for smallness to be defined relative to the modal size. So defined, the seeds to be rejected should be only a small proportion of the total output of an orchard. Turning now to Table 2, a separate rejection criterion will be necessary for the different orchards, since the seeds of size grade I of orchard No. 3,

size grades II and I of orchard No. 32, and size grades III, II, and I of orchard No. 2 need be rejected as small.

The maximum germination appears to be associated with the seed of that size which occurs most frequently in an orchard. The seed of a size far removed from the modal size tends to germinate poorly. This again suggests that the absolute size of seed is not the deciding criterion for rejecting small seeds; the deviation from the modal size which characterizes a seed population would appear to be the factor of importance.

The foregoing consideratons show that the practice of using a common mesh for sieving out small seeds has caused a considerable wastage of good seeds. This can be avoided if the mesh size is decided with reference to the common seed-size of an orchard. Only those seeds which are notably small for a particular orchard need be discarded.

Acknowledgements. The author is grateful to Dr. W. Wight under whose direction the data reported in this paper were collected. Thanks are also due to the Director, Tocklai, and the Indian Tea Association for permission to publish.

REFERENCES

1. J. A. Leliveld, *Arch. Koffiecult. Ned-Ind.*, 1938, **12**, 127.
2. F. R. Tubbs, *Bull. Tea Res. Inst. Ceylon*, No. 8, 1930, p. 23.
3. J. W. Gregor, *New Phytol.*, 1946, **45**, 254.
4. E. J. Salisbury, *The Reproductive Capacity of Plants*, London, G. Bell & Sons Ltd., 1942, p. 35.

(*Received 12 February 1960*)

GROUNDNUT VARIETIES OF NORTHERN RHODESIA AND THEIR CLASSIFICATION

J. SMARTT

(*Plant Breeder, Central Agricultural Research Station, Mount Makulu, Northern Rhodesia*)

Summary

A collection of Northern Rhodesian groundnut varieties is described. It has been possible to classify most of the forms in accordance with Bunting's system. Additional groups have been added, to include some new and previously undescribed forms. These groups extend the recorded range of homologous variation within and between the principal sections of the species. In particular, runners of the *Matevere* group, and runners with a range of testa colours, have been encountered.

THE groundnut is a popular African food crop in most areas of Northern Rhodesia. It is mostly grown for local use, but the Eastern Province produces an annual surplus of about 6,000 tons of kernels. It is little grown by European farmers at present. As a result, relatively few new varieties have recently been introduced to the Territory. Almost all the varieties found at the present time are those which the local African tribes have carried with them on their complex migrations. The principal migration stream has been roughly from north to south, but superimposed on this have been return migrations northwards and minor migrations from the east and west [1, 2, 3]. Only three varieties are known to owe their introduction to European agency, viz. Natal Common, Valencia Bunch (incorrectly called Virginia Bunch), and the true large-seeded Virginia Bunch. All three are grown in the Union of South Africa and this is the obvious source of these three varieties in Northern Rhodesia.

The collection and study of local varieties was started in late 1954.

System of Classification

The Tozi (Sudan) classification of groundnut varieties [4, 5] has been applied in this work. It appears to be comprehensive and practicable, the diagnostic characters are, on the whole, clear-cut, and with practice are usually easy to apply.

Bunting selects the mode of branching as the discriminant character for his first major division of the species. Two types of branching are known, which he terms 'alternate' and 'sequential'. In alternate branching, pairs of vegetative and reproductive branches alternate on the first-order branches of the main stem. In sequential branching there is no such alternation, but reproductive branches follow each other in sequence at the nodes of the first-order branches of the main axis. A major division of the alternately branched section is based on habit, which may be erect (spreading bunch) or prostrate (runner). All the sequentially branched forms have the upright bunch habit. The further

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

breakdown into varieties is based largely, in both sections, on pod and kernel characters.

The two main sections thus defined are quite distinct in their agronomic features. Sequentially branched (upright bunch) varieties are almost always early maturing, without seed dormancy and particularly susceptible to damage by Cercospora leafspots. Alternately branched varieties take longer to mature, while the seeds possess dormancy. They are, on the whole, more resistant to Cercospora leafspots and usually darker green in colour than the sequentially branched forms.

General Characters of Local Varieties

Most Northern Rhodesian groundnut varieties have alternate branching and the prostrate habit. An alternately branched bunch form was collected from a Mambunda village in the Barotseland Protectorate. This is the only spreading bunch form so far found in the country which is not an obvious recent introduction. Virginia Bunch, which has a similar habit, was introduced into the Eastern Province many years ago.

Bunch varieties with sequential branching are found in African cultivation in various parts of the Territory, particularly in the south and towards the north-east. The two sequential bunch varieties found in the Southern Province, *Natal Common* and *Valencia*, are obviously comparatively recent introductions from the Union of South Africa.

The naming of groundnut varieties in Northern Rhodesia is confused. Numerous English as well as African names for a popular variety may be found. A variety which corresponds closely with the American *Jumbo Runner* is known in the Eastern Province as Chalimbana, in the Northern Province as Mayoba, and in some quarters as African Giant. The naming of locally grown *Valencia* strains is even less precise. The *Valencia* type is known in the Union of South Africa by the name of Virginia Bunch and in Southern Rhodesia as Rhodesian Spanish Bunch. Both these names are current in Northern Rhodesia and both are misleading, particularly because the true *Virginia Bunch* and also *Spanish Bunch* occur in the Territory. The name *Valencia* is standard in international usage and should replace the present names.

In the northern part of the country vernacular names are exclusively used for distinct varieties in both the alternately and sequentially branched sections. It may be inferred from this that both sections have long been established in that area. In the Southern Province, where sequentially branched varieties have been introduced within living memory, the English names are widely used.

Although generally similar in habit, local groundnut varieties differ among themselves in pod and kernel characters. Other differences have been noted which could not be used diagnostically without detailed biometrical study. On Bunting's classification most of the local Northern Rhodesian strains can be placed in the *Jumbo*, *Kongwa*, and *Indian Runner* groups. There appear to be no local representatives of the *Natal Runner* or *Nambiquarae* groups. Runner homologues of Bunting's

Matevere group have been collected in many districts throughout the Territory.

A number of alternately branched runner varieties with red, white, and purple kernels have been found. In the alternately branched group the testa colour is usually russet-brown. Only two variety groups with kernels of other colours are included in the Tozi classification: *Asiriya Mwitunde*, a spreading bunch form with red kernels; and *Nambiquarae*, a runner with variegated red and white testa.

Variety Groups represented in Northern Rhodesia

The following variety groups occur in Northern Rhodesia:

Sequentially Branched Section

Valencia (misnamed Virginia Bunch or Rhodesian Spanish Bunch) is commonly grown in the Southern and Central Provinces. A *Valencia* variety called Solontoni occurs in the Northern Province.

Purple Valencia. This type has been found so far only in the Northern Province where it is known by the vernacular name Chiyeye.

Manyema Bunch; *Spanish Bunch*; *Natal—Barberton*. Varieties of these three groups are to be found in the Northern Province, very often mixed. They are known as Chimonko in the vernacular. *Natal Common* has been introduced in comparatively recent times into the Southern and Central Provinces and less extensively elsewhere. It is usually known under its English name.

Alternately Branched Section: Spreading Bunch Forms

Virginia Bunch. A known introduction to the Eastern Province.

Fung Bunch. Mambunda was separated from a mixture collected in the Mankoya District of Barotseland.

Alternately Branched Section: Runner Forms

Jumbo. This group is known in many areas of the Territory. It is known as Chalimbana in the Nyanja dialects of the Eastern Province, Mayoba in the Bemba of Northern Province, and Nyandongo in the Lozi of the Barotseland Protectorate. A similar but somewhat smaller type in the Eastern Province is called Nsenga after the tribe which grows it.

Kongwa Runner. Typical representatives of this group are found in most parts of the Territory. In the Southern Province this type is called Chitonga from the name of the principal tribe of the area. In Barotseland a variety of this type is called Kasakala. Elsewhere the type is found in the Northern and Luapula Provinces.

Indian Runner. Some Northern Province material approaches this group in smallness of pod but is slightly larger than the typical forms. The boundary between this and *Kongwa* is not absolutely clear cut.

The remaining local runner varieties do not fit into any of the Tozi groups. New group names have accordingly been chosen.

Large Kongwa Runner, with two russet-brown kernels, and pods larger than those of *Kongwa Runner* but resembling them in texture.

The kernel size approaches *Jumbo Runner*. This type has been collected from the Eastern and Northern Provinces, also the Barotseland Protectorate.

The next four groups are testa-colour variants in the runner series with two kernels.

Red Kongwa Runner. Plant and pod characters are like *Kongwa Runner*, but the testa is red. Northern Province.

White Kongwa Runner. This type is a *Kongwa Runner* with a white testa. Northern Province, where the vernacular name is Kaipike.

Purple Large Kongwa. Similar to *Large Kongwa Runner* except for the purple testa; found in the Eastern Province, but reported by those from whom it was collected to have originated in the Belgian Congo.

Red Jumbo Runner. This is a large-seeded, red-kernel type. The pod is rather shorter than the typical *Jumbo Runner* pod, but is otherwise similar.

The next four groups have characteristically more than two kernels, a feature not included, so far as runners are concerned, in the Tozi classification, although pods with more than two kernels are not infrequently produced by *Nambiquarae* groundnuts. These include the runner homologues of the *Matevere* group, in the sense of [5].

Mayoba. This is the vernacular name in the Northern Province for the largest-podded groundnut varieties. It is locally applied to *Jumbo* types as well, but for the present purpose it is restricted to the largest two-, three-, or four-kernelled types of runner groundnuts, with large, coarse pods, resembling those of *Jumbo Runner*.

Large Chimbuwila and *Chimbuwila*. *Chimbuwila* and similar names are used extensively throughout the Federation of Rhodesia and Nyasaland to describe local runner-groundnut varieties with medium-sized pods. Some runner material obtained from Nyasaland under this name contained forms having pods with two, three, or four kernels. The names *Large Chimbuwila* and *Chimbuwila* have been assigned to the two-, three-, or four-kernelled types corresponding to *Large Kongwa Runner* and *Kongwa Runner* respectively. Both types have been collected from the Southern, Eastern, Luapula, and Northern Provinces and from the Barotseland Protectorate; and in addition the former has been found in the North Western Province.

Purple Chimbuwila. A form of *Chimbuwila* with a purple testa was isolated from a mixed sample obtained in the Luapula Province. This has maintained itself since 1956 as a true-breeding strain.

It is now clear that the sequentially branched section and the runner forms of the alternately branched section display similar ranges of testa colours, though it is not clear why colours other than russet brown are so much less in evidence among the runners. More intensive search may be expected to produce a similar range of variation in the spreading bunch forms also. The East African spreading bunch variety Asiriya Mwitunde has red kernels, while Mani Pintar is a spreading bunch form in which the testa colour resembles that of *Nambiquarae* in being

variegated red and white. A very interesting development of this study in the genetic field would be an attempt to transfer pigment genes between sequentially and alternately branched forms.

A Revised Key to the Groups of Runner-Groundnut Varieties

A modification of the relevant part of the revised Tozi key [5], to include the new forms, is given below.

Branching alternate, habit prostrate:

1.	Kernels variegated (red and white)	*Nambiquarae*
	Kernels not variegated	2.
2.	Pods typically unconstricted	*Natal Runner*
	Pods typically constricted	3.
3.	Pods large, coarsely marked, shell very thick	4.
	Pods medium-large to large, markings not coarse, shell not especially thick	6.
	Pods medium in size	8.
	Pods small	*Indian Runner*
4.	Kernels: two	5.
	Kernels: two, three, or four	*Mayoba*
5.	Kernels red	*Red Jumbo Runner*
	Kernels brown	*Jumbo Runner*
6.	Kernels: two	7.
	Kernels: two, three, or four	*Large Chimbuwila*
7.	Kernels purple	*Purple Large Kongwa Runner*
	Kernels brown	*Large Kongwa Runner*
8.	Kernels: two	9.
	Kernels: two, three, or four	10.
9.	Kernels red	*Red Kongwa Runner*
	Kernels white	*White Kongwa Runner*
	Kernels brown	*Kongwa Runner*
10.	Kernels purple	*Purple Chimbuwila*
	Kernels brown	*Chimbuwila*

In the Tozi groundnut collection, a number of theoretically possible combinations of habit, testa colour, and pod type were not represented. The present work adds to the known combinations of these characters. No doubt many undescribed forms still exist or could be produced by hybridization and selection.

The origin of unusually pigmented runner strains in Northern Rhodesia can for the present only be guessed. They may have entered the country with the early importations, or they may have arisen in Central Africa by mutation or hybridization. They are not abundant and have in some cases been separated from mixed samples in which they form an infinitesimal part only of the normal crop. The mutation hypothesis is purely speculative, particularly as the nature of the genetic control of testa colour is not fully known. There is a distinct possibility that

hybridization between sequential forms with pigmented testas and normal russet-brown-seeded types, followed by segregation, could have given rise to some, if not all, of the testa pigment variants described. No white-seeded sequential form is known in agriculture in Northern Rhodesia, but such forms are known in Southern Rhodesia (H. C. Ducker, personal communication). Hybridization, although rare, undoubtedly does occur naturally in the crop.

Some workers on groundnut varieties in southern Africa (J. Sellschop, H. C. Ducker; personal communications) believe that considerable development of new groundnut varieties has taken place in Africa since the crop was first introduced. It would be most interesting to compare comprehensive collections of African and South American groundnut varieties from this point of view.

Acknowledgements. Professor A. H. Bunting has seen pod and kernel material of the new forms, and has helped in the preparation of this paper. Thanks are also due to W. J. R. Boyd and other members of the extension staff of the Department of Agriculture who supplied much of the material. The author is indebted to the Director of Agriculture, Northern Rhodesia, for permission to publish this paper.

REFERENCES

1. C. G. TRAPNELL and J. N. CLOTHIER, *The Soils, Vegetation and Agricultural Systems of North-Western Rhodesia*, Lusaka, Government Printer, 1957.
2. —— *The Soils, Vegetation and Agriculture of North-Eastern Rhodesia*, Lusaka, Government Printer, 1953.
3. W. V. BRELSFORD, *The Tribes of Northern Rhodesia*, Lusaka, Government Printer, 1957.
4. A. H. BUNTING, *Empire J. Expt. Agric.*, 1955, **23**, 158.
5. ——ibid., 1958, **26**, 254.

(*Received 29 February 1960*)

NOTE ON THE DAILY GRAZING DISTANCES OF SIX ROMNEY EWES, THREE OF WHICH WERE TREATED WITH L-THYROXINE

E. CRESSWELL,[1] A. H. KIRTON, AND D. F. G. ORWIN

(*Massey Agricultural College, New Zealand*)

WITH PLATE 3

Summary

A preliminary experiment on the effect of L-thyroxine injection on the daily mileages of three Romney ewes has been carried out. Over the three weeks of the experiment both the treated and the control animals increased their daily travel. On average the travel of the thyroxine group increased more than that of the control ($0{\cdot}05 < P < 0{\cdot}10$). The sheep tended to raise or lower their daily travel as a single group and the general mean daily distance travelled was 1·6 miles.

IT is known that thyroxine increases the metabolic rate and the irritability of animals. The object of this preliminary experiment was to find out if the daily grazing distances of Romney ewes could likewise be influenced by treatment of the animals with thyroxine.

Materials and Methods

The experiment was carried out between 16 April and 6 May (autumn) 1958, using six mature Romney ewes ranging in weight from 103 to 127 lb. The ewes were kept in a 3·5-acre flat paddock, and each was fitted with a rangemeter that recorded the daily mileage of the animal. Rangemeters have been described by Cresswell [1, 2] and Cresswell and Harris [3]. Fig. 1 (Plate 3) shows sheep harnessed to rangemeters. When the ewes had become completely accustomed to the equipment three were injected subcutaneously with 9 mg. L-thyroxine, in alkaline solution each, on three successive days: 19, 20, and 21 April. The level of thyroxine administration was determined by work reported elsewhere [4].

Throughout the experiment records of the daily distance travelled were made at 8.0 a.m. One-tenth of a mile was subtracted from each record to allow for the distance the sheep travelled to the pen when they were mustered. The animals were always mustered from the same area of the field.

Results and Discussion

Interference with the distance recorder by cut grass and thistles led to the discarding of 12 observations out of 126 (Table 1). Based on 113 individual records the mean distance travelled by the ewes was 1·6 miles per day (range 0·9–2·8 miles). This value is slightly higher than that observed on a weekly basis for Romney ewes in a 6-acre flat paddock [2]. Table 1 also indicates that, as on 26 April, the animals' mileages

[1] Present address: The Rowett Research Institute, Bucksburn, Aberdeen, Scotland.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

TABLE 1. *Net Daily Distances travelled by Romney Ewes on a 3·5 acre Flat Lowland Pasture between 16 April and 6 May 1958, inclusive*

Ewe	*1st week daily mileages*						
1	1·2	1·4	1·4	..	1·5	1·6	1·4
2	1·1	1·1	1·4	1·7	..	1·5	1·3
3	..	1·1	1·7	1·9	1·3	1·6	1·3
4	1·0	1·5	1·8	1·7[a]	1·4[a]	1·6[a]	1·6
5	0·9	0·9	1·3	1·5[a]	1·2[a]	1·3[a]	0·9
6	[b]	1·2	1·3	1·6[a]	1·7[a]	1·5[a]	1·3

[a] Injected with 9 mg. L-thyroxine per day on 19, 20, and 21 April.
[b] Started one day late.

Ewe	*2nd week daily mileages*						
1	1·5	1·8	1·4	2·3	1·5	1·3	1·9
2	1·5	1·5	1·3	2·0	1·2	1·2	1·6
3	1·5	1·9	..	2·4	1·6	1·5	1·9
4	1·3	..	1·8	2·6	1·8	1·7	2·2
5	1·1	1·4	1·3	2·1	1·3	1·1	..
6	1·5	1·7	1·5	2·8	1·5	1·5	2·2

Ewe	*3rd week daily mileages*						
1	1·7	1·9	2·6	1·8	1·9	2·0	1·6
2	1·3	1·2	1·9	1·5	1·4	1·5	1·2
3	1·8	1·8	2·5	1·8	..	..	1·6
4	..	2·2	2·5	1·6	1·9	..	1·6
5	1·7	1·9	2·6	..	2·0	2·1	1·7
6	..	2·8	2·6	1·9	2·0	2·1	1·5

TABLE 2. *Weekly Mean Net Daily Mileages of Six Ewes, Three of which were Treated with L-thyroxine*

	1st week			*2nd week*			*3rd week*		
Ewe	*n*	*Mean*	*S.D.* ±	*n*	*Mean*	*S.D.* ±	*n*	*Mean*	*S.D.* ±
1	6	1·4	0·1	7	1·7	0·3	7	1·9	0·3
2	6	1·4	0·2	7	1·5	0·3	7	1·4	0·2
3	6	1·5	0·3	6	1·8	0·3	5	1·9	0·4
4[a]	7	1·5	0·3	6	1·9	0·4	5	2·0	0·4
5[a]	7	1·1	0·2	6	1·4	0·4	6	2·0	0·3
6[a]	6	1·4	0·2	7	1·8	0·5	6	2·2	0·5

n = Number of observations on which the mean is based.
[a] = Injected with 9 mg. L-thyroxine per day on 19, 20, and 21 April.

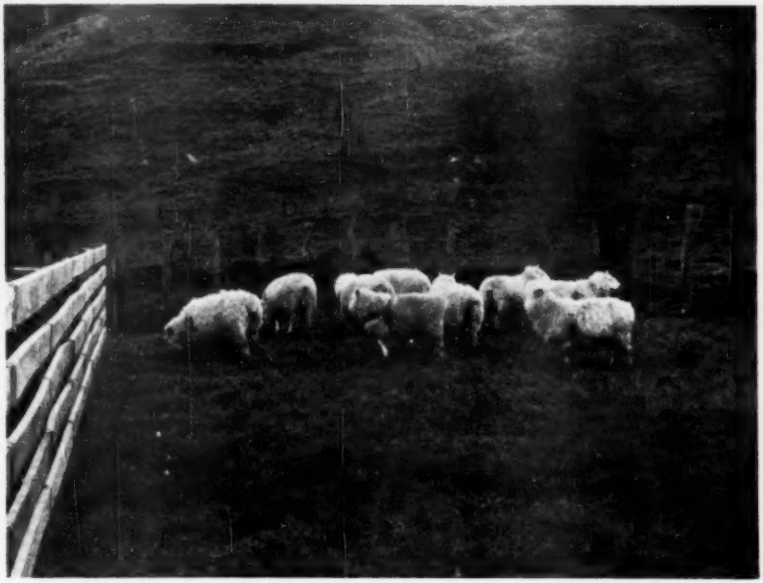


FIG. 1. A group of sheep equipped with rangemeters.

tended to move up or down as a group. This effect has been found in other rangemeter studies [2, 3].

The average daily mileages for all animals except ewe 7 increased from the first to the second and from the second to the third weeks of the experiment (Table 2). On average the L-thyroxine-treated ewes covered a lower mileage than the control animals during the first week of the experiment, a similar mileage in the second week, and a higher mileage during the last week. Thus on average the L-thyroxine-treated sheep increased their daily travel more than the control animals. This difference between the groups was not significant at the $P = 0{\cdot}05$ level, but the indications were that the difference may have been a real one ($0{\cdot}05 < P < 0{\cdot}10$).

Acknowledgements. The senior author acknowledges the financial support of the Research Committee of the University of New Zealand. A supply of 30 mg. tablets of purified L-thyroxine was kindly provided by Glaxo Laboratories (N.Z.) Ltd.

REFERENCES

1 E. Cresswell, *Brit. J. Anim. Behav.*, 1957, **5**, 119.
2. —— ibid., 1960, **8**, 32.
3. —— and L. E. Harris, *J. Anim. Sci.*, 1959, **18**, 1447.
4. A. H. Kirton, E. Cresswell, F. R. Cockrem, and G. W. Butler, *N.Z. J. Agric. Res.*, 1959, **2**, 1143.

(*Received 24 March 1960*)

NOTE ON THE EFFECT OF SHEARING, AND OF DRENCHING WITH SIMULATED RAIN, ON THE OXYGEN CONSUMPTION AND RESPIRATORY PATTERN OF SHEEP

E. CRESSWELL[1]

(*Massey Agricultural College, New Zealand*)

WITH PLATES 4, 5, 6

Summary

The effect of shearing, and of drenching with simulated rain, on the respiratory pattern and oxygen consumption of sheep has been investigated, using Romney Marsh and Cheviot ewes. Shearing resulted in a two-thirds reduction in the respiration rate and a large increase in the depth of breathing.

A three-minute spraying with simulated rain reduced the respiration rate, and increased the depth of breathing and the oxygen consumption, of ewes which had recently cast their fleece or had been shorn.

AT the beginning of November 1956 some of the tracheotomized sheep which were being used in an indirect calorimetry project [1, 2] began to cast their wool. It was therefore decided to discontinue regular metabolism studies for the time being, as it was not then known whether variations in fleece-cover affected oxygen consumption. Ritzman and Benedict [3] report the effect of temperature changes on the energy metabolism of sheared sheep but not the effect of shearing itself, which is surprising, since they maintained that sheep offer a striking illustration of the effect of covering on their adaptability to changes in environmental temperature. The opportunity was therefore taken to study the effect of shearing on the energy metabolism of as many animals as possible.

Starting on 23 November 1956, normal oxygen spirometer recordings were taken, using eleven sheep, for 5 days following several days of preliminary recordings. On the fifth day seven of the sheep were sheared following early morning oxygen spirometer recordings. Of the remaining sheep, three Cheviots had cast their wool prior to the commencement of this work and the fourth, a Romney, was left unsheared to act as control. Metabolism recordings were made shortly after shearing and on following days. When compared with charts made before shearing it was obvious that shearing had resulted in an abrupt change in the respiratory pattern of the shorn animals. In these animals the respiration rate fell by approximately two-thirds and the depth of breathing was almost doubled (Fig. 1, Plate 4). Four of the sheared sheep showed increases in oxygen consumption (Table 1).

On 13 December 1956 ten of the sheep were utilized for study of a further aspect of climatological work. A routine oxygen-consumption record was taken from each animal. Each animal in turn was then subjected to a soaking with simulated rain for 3 minutes. The sheep were then reconnected to the oxygen spirometer and recordings taken. It was found that although the animals did not appear to be disturbed, the

[1] Present address: The Rowett Research Institute, Bucksburn, Aberdeen, Scotland.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

TABLE 1. *Oxygen-Consumption Records (litres O_2/5 minutes)* of Eleven Sheep; (1) pre- and post-shearing; (2) pre- and post-wetting after shearing; (3) routine recordings with an 8-minute time interval*

		Cheviots					*Romneys*					
Date		*8*	*10*	*20*	*6*	*7*	*21*	*16*	*5*	*4*	*2*	*15*
23/11/56	Normal	1·13	†	1·41	1·32	1·33	1·41	1·60	1·33	1·55	1·14	1·32
26/11/56	,,	1·52	1·69	1·23	1·71	1·43	1·43	1·43	†	1·71	1·14	1·43
27/11/56	,,	1·32	1·52	1·43	1·81	1·32	1·13	1·60	1·14	1·41	1·13	1·41
28/11/56	,,	1·23	1·52	1·22	1·41	1·51	1·23	1·13	1·22	1·41	1·13	1·42
29/11/56	Pre-shearing	1·04	1·43	†	1·23	1·32	1·32	1·41	1·42	1·33	1·13	1·51
		sheared	*no wool*	*no wool*	*no wool*	*sheared*	*sheared*	*sheared*	*sheared*	*control*	*sheared*	*sheared*
29/11/56	Post-shearing	1·31	..	..	..	†	1·73	1·49	1·59	†	1·12	1·49
30/11/56	..	1·38	1·34	..	1·29	1·43	1·38	1·58	1·52	1·33	1·53	1·34
1/12/56	..	1·43	†	..	1·43	1·42	1·42	1·57	1·37	1·32	1·57	1·43
2/12/56	..	1·43	1·52	..	1·66	1·42	1·72	1·62	1·57	1·38	1·42	1·57
13/12/56	Pre-wetting	1·48	1·50	1·41	1·54	..	1·59	1·59	1·31	1·45	1·13	1·50
13/12/56	Post-wetting	1·57	1·69	1·50	1·87	..	1·87	1·97	1·97	1·45	2·44	1·68
19/12/56	Normal	1·28	1·38	1·49	..	1·28	1·65	1·58	1·28	1·47	1·37	1·63
						Eight-minute interval						
	..	1·28	1·38	1·49	..	1·28	1·65	1·58	1·28	1·47	1·37	1·63

* Corrected to standard temperature and pressure. † Cannula leak.

soaking with water had a marked effect on the respiratory pattern (Figs. 2 and 3, Plates 5, 6). In every case the respiration rate decreased, the depth of breathing increased, and (except for one Romney which still carried a full fleece) the oxygen consumption rose (Table 1). Six days later, ten of the sheep were recorded twice, with an 8-minute interval between recordings. The 8-minute interval was estimated as being equivalent to the period between recordings before and after soaking. No change occurred in any of the records (Table 1). This confirmed earlier exploratory work (unpublished data) into the repeatability of records made within a few minutes of each other.

On 28 December 1956 a final recording was taken from all animals. The charts revealed that one month after shearing, and in summer temperatures, the respiration rhythm was still slower and deeper than it was before shearing.

Acknowledgement is made of the financial support of the Research Committee of the University of New Zealand and Massey Agricultural College.

REFERENCES

1. E. CRESSWELL, *Nature*, Lond., 1957, **179**, 1139.
2. —— Ph.D. Thesis, 1958, lodged in Massey Agricultural College Library.
3. E. G. RITZMAN and F. G. BENEDICT, *Carn. Inst. Wash.*, 1938, Pub. **494**, 109.

(*Received 7 March 1960*)

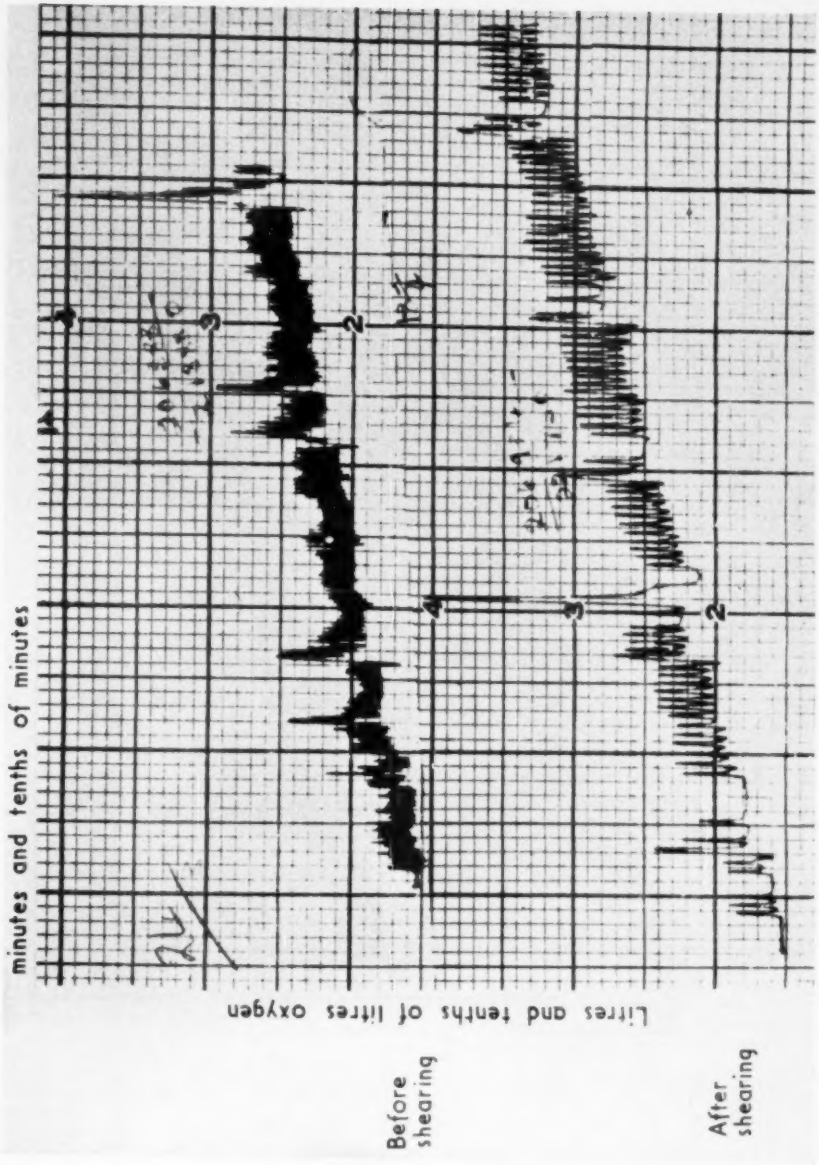


FIG. 1. The respiratory pattern of a sheep before and after shearing.

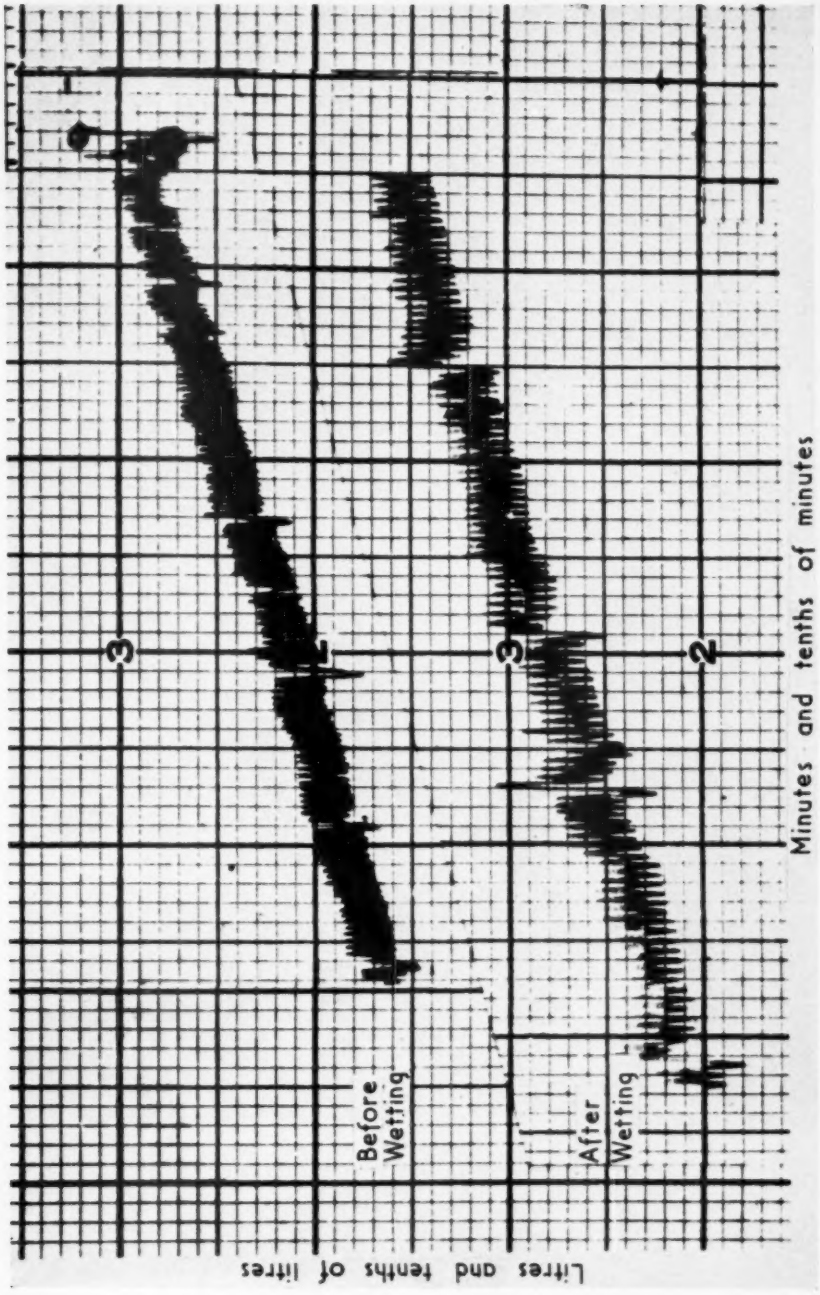


FIG. 2. The respiratory pattern of an unshorn sheep before and after wetting.

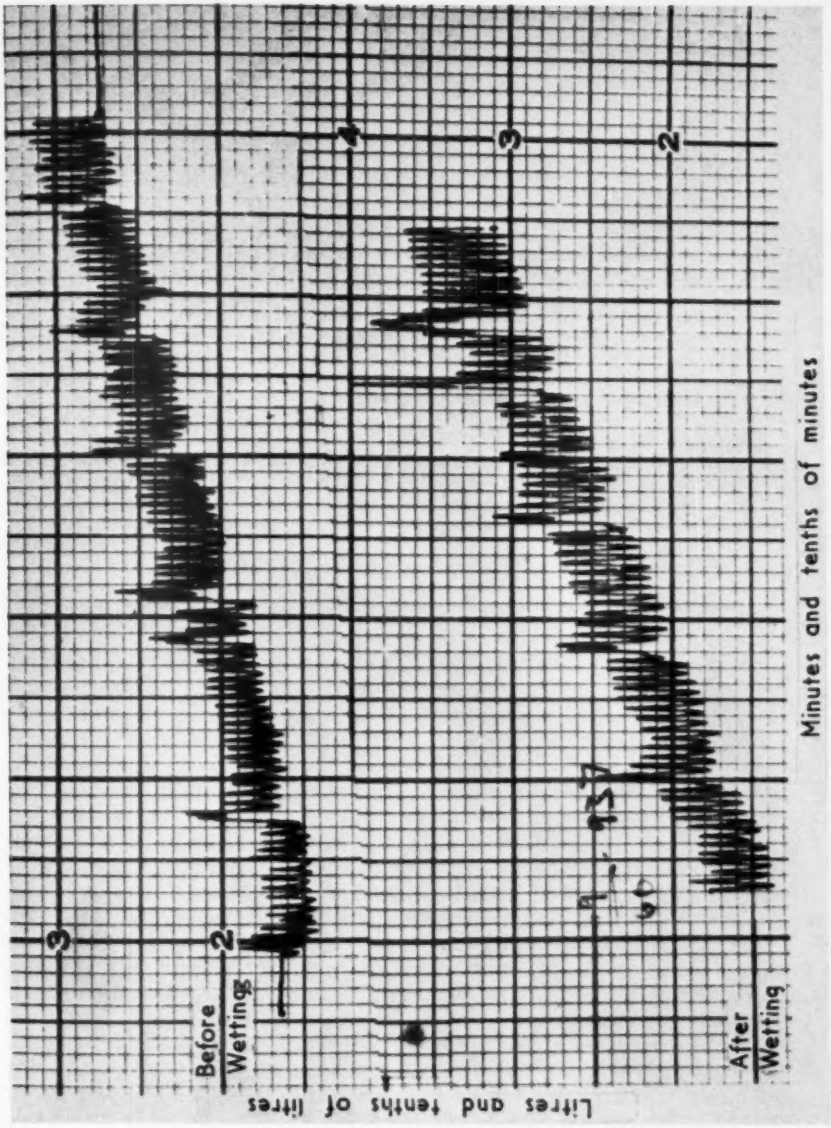


FIG. 3. The respiratory pattern of a shorn sheep before and after wetting.

STUDIES ON THE ROOTS OF LEYS AND THE ORGANIC MATTER AND STRUCTURE OF THE SOIL

ARTHUR TROUGHTON

(*Welsh Plant Breeding Station, Aberystwyth*)

Summary

An investigation was made into the effects of geographical location, year of measurement, and botanical composition of a ley upon the root weight and the percentages of organic matter and water-stable aggregates in the soil.

In general the effect of a particular factor was the same on all three measurements in that all were increased or decreased; each measurement, however, was not affected to the same extent, root weight varying more than the others. The magnitudes of the measurements decreased with increasing distance from the surface, and it was in the upper few inches of the soil, where the magnitudes were greatest, that the experimental treatments had their greatest effect.

The measurements varied greatly with the location of the ley and no single factor was found which could account for the differences. At any particular place and depth of the experimental treatments it was the year in which the measurements were made which had the greatest influence upon their magnitudes. All three measurements increased in the 0–3-in. layer from the time of sowing until about the fourth year.

Of the seeds mixtures which were studied, a modified Cockle Park mixture, and one of *Lolium perenne* and *Trifolium repens*, produced the greatest root weight. The other measurements were only slightly influenced by the botanical composition of the sward.

In a system of alternate husbandry the two functions of a ley are to provide herbage for animal food, and to improve fertility of the soil for the benefit of succeeding arable crops. The roots of the plants are associated with both these functions, for without an adequate root system a plant is incapable of producing the maximum quantity of herbage, whilst the improvement of soil fertility depends largely upon the ability of a ley to add organic matter to the soil and thus improve its physical structure—two processes in which roots play a major part.

Although theoretically the plant as a unit may live indefinitely, the components of a grass plant, the roots and tillers, have a limited length of life [1, 2]. The weight of roots under a sward at any one time is therefore the result of the balance between the growth of the new and the decay of the old. The organic matter in a soil growing a ley is the result of the balance between the addition of fresh material from the grass roots, old leaves and animal excreta, and the mineralization of the material already in the soil. Under a ley the former process is usually greater than the latter, giving a net increase in organic matter [3]. The improvement of the physical structure of the soil by a ley is brought about partly by the direct physical action of the roots and partly by the effect of the additional organic matter [2].

The three measurements, root weight, organic matter, and physical structure, have been studied separately by a number of workers but rarely have they been studied together. The object of the present

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

3968.114 M

investigation was to study the influence of botanical composition, location, and age of the ley, on all three measurements.

Description of the Experiment

A 5×5 Latin square was sown in four fields in Wales and Shropshire. The five treatments within the squares were the following seeds mixtures:

	lb./acre					*lb./acre*
(1) *Lolium perenne* S.101	16	plus	*Trifolium repens* S.184			2
(2) *Festuca pratensis* S.53	24	,,	,,	,,	,,	2
(3) *Phleum pratense* S.48	14	,,	,,	,,	,,	2
(4) *Dactylis glomerata* S.26	16	,,	,,	,,	,,	2
(5) *Lolium perenne* S.101	16					
Festuca pratensis S.53	4	,,	,,	,,	,,	2
Dactylis glomerata S.48	8					

The seeds were sown in the spring of 1951. The plots were unfenced, and surrounded by land sown with the farmer's seeds mixture. The

TABLE 1. *Analysis of the Soils, 0–9 in.*

	pH	*Exchangeable* CaO %	*Soil* P_2O_5 %	*Soil* K_2O %	*Coarse sand* %	*Fine sand* %	*Silt* %	*Clay* %
Aberystwyth	5·5	0·223	0·0038	0·008	3	15	32	27
Munslow	5·4	0·250	0·0093	0·008	7	50	14	14
Talgarth	5·2	0·143	0·0048	0·006	11	46	20	13
Manorbier	6·7	0·408	0·0075	0·007	13	41	20	16

Chemical analysis—mean of 1950–7 for Talgarth and Munslow;
,, ,, 1950–2 for Aberystwyth and Manorbier.
Mechanical analysis determined by 1927 International Method.

experimental area was managed by the farmers in the same manner as the remainder of the field. The plots were 8×8 yds. except at Aberystwyth where they were 2×2 yds.

The descriptions of the fields are as follows:

Aberystwyth, Cardiganshire. Wet valley bottom, 345 ft. above sea-level, heavy clay soil. Sown direct after one year's fallow, having previously been in permanent grass.

Munslow, Shropshire. Dip slope of Wenlock Edge, 500 ft. above sea-level. Thin acid soil derived from Aymestry limestone. Sown direct after several years in arable.

Talgarth, Breconshire. Valley bottom in the foothills of the Eppynt mountains, 475 ft. above sea-level. Soil derived from Old Red Sandstone. Seeds sown under spring wheat after several years in arable.

Manorbier, Pembrokeshire. Quarter of a mile from the sea and 175 ft. above it. Soil derived from magnesian limestone. Seed sown under barley after a number of arable crops.

Further details of the soils are given in Table 1.

At the time of sowing, and subsequently each spring and autumn,

samples of soil were taken for the determination of soil organic matter and physical structure. The weight of roots was determined from the spring of 1952 onwards. The trials at Aberystwyth and Manorbier ceased after 1953 and the others after 1957.

The two determinations each year have been averaged in an endeavour to overcome any bias from sampling annually at a slightly different time in the cycle of seasonal changes. Root weight and physical structure of the soil are known to vary during the year [4, 5] and this may also be true of soil organic matter. The analyses of variance used to interpret the results were of the Error *a* and Error *b* type.

Methods Employed

Root Weight

The method of determining the root weight has been described in a previous paper [4]. Soil samples were taken with a 3-in. core sampler designed to prevent compression of the sample, one sample from each plot, sampled to a depth of 9 in., the subsequent core being divided into 0–3-in., 3–6-in., and 6–9-in. layers.

The tillers on the top of the 0–3-in. layer were counted and the herbage cut off. The soil samples were soaked in water for a maximum of 24 hours, after which the soil was removed from the roots by a gentle spray of water, with decantation and straining through a 50-mesh sieve. The roots were then dried at 105° C. Prior to weighing, leaf bases were detached and discarded.

Soil Organic Matter

This was estimated by determining the percentage of organic carbon. Five cores of 1 cm. diameter were taken to a depth of 9 in. from each plot, divided into three 3-in. layers, and the soil from each layer within a plot bulked. The percentage of organic carbon in each bulked sample was determined by the Walkley and Black wet combustion method [6]. The grinding of the soil prior to digestion was done by hand, and during this process, and the subsequent sieving, all visible pieces of organic matter, principally roots, were removed.

Physical Structure of the Soil

This was measured by determining the water stability of soil aggregates. The technique adopted closely followed that described by Russell and Tamhane [7] and Russell (personal communication, 1950). Soil samples were obtained in the same manner as for root weight, and were air-dried. One hundred grammes of air-dry aggregates which would pass through a ½-in. square sieve but be retained by one of 5 mesh (3·353 mm. aperture) were wetted by capillary absorption, and transferred to the top of a bank of sieves of 5, 16, and 30 mesh (3·353, 1·003, and 0·500 mm. aperture). The bank of sieves was then dipped in the water ten times, the water being allowed to rise nearly to the top of the rim of the uppermost sieve but not to run over it. The uppermost sieve was removed and the dipping process repeated five times. Finally the 16-mesh sieve was removed and the 30-mesh sieve dipped by itself five times; the

soil remaining on the sieves was dried and weighed. By careful hand grinding, stones larger than 0·5 mm. were separated from the small particles and weighed. The weight of stone-free soil remaining on the sieves, expressed as a percentage of the original weight of stone-free soil, will be referred to as the percentage of water-stable aggregates.

Results

Location of the Ley

Within any one year the magnitudes of the measurements varied considerably between the farms (Table 2). There was a gradual decline in root weight from Aberystwyth, through Munslow and Talgarth to

TABLE 2. *Magnitudes of the Measurements at each Location. Mean of 1952–3*

		Percentage		*Number of tillers/sq. ft.*		
Location	*Root weight lb./acre*	*Organic carbon*	*Water-stable aggregates*	*Sown grasses*	*Trifolium repens*	*Total*
Aberystwyth	14,300	3·8	77	301	0	417
Munslow	10,200	3·1	76	419	31	568
Talgarth	8,600	1·9	51	417	33	465
Manorbier	7,000	2·0	50	285	44	339

Manorbier. The percentage of organic carbon showed a similar gradation except that the values for Talgarth and Manorbier were nearly identical. The percentage of water-stable aggregates was almost the same for Aberystwyth and Munslow, and for Talgarth and Manorbier. There was thus a certain parallelism between the measurements. These variations in the magnitudes of the measurements could not be related to the density of the sward nor to any of the soil properties included in Table 1, with the exception of coarse sand; nor was it possible to relate them to the available meteorological data [8, 9].

The relative distribution of the roots, organic matter, and water-stable aggregates between the three soil layers varied little between the farms.

Year of Sampling

For brevity, the results of only Talgarth and Munslow have been discussed in detail in relation to the year of sampling. Seven years' data were available from these farms as against only three from Aberystwyth and Manorbier, and in general the results from the latter two farms agreed with those from Talgarth and Munslow.

Of the influences studied, year of sampling had the greatest effect. A large weight of roots was produced during the first year after sowing; thereafter the weight increased steadily until the fourth harvest year, 1955. This was followed by a decrease between the fourth and fifth years and an increase between the fifth and sixth (Table 3). Most of the root weight occurred in the 0–3-in. layer and it was there that the greatest

changes took place. As the sward aged the proportion of root weight in the lower soil layers tended to decrease.

Large numbers of tillers were produced during the year after sowing; thereafter the number remained more or less constant, although the botanical composition tended to change, the sown grasses being replaced by other species. Dicotyledonous weeds were infrequent in all swards.

TABLE 3. *Magnitudes of the Measurements in each Year*

Year	*1951*	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*	*L.S.D.**
Root weight (lb./acre)								
Munslow								
0–3 in.	..	6,700	7,300	8,300	10,900	8,700	9,400	810
3–6 in.	..	2,400	2,200	2,300	1,700	2,200	360	
6–9 in.	..	800	900	800	800	600	400	150
Talgarth								
0–3 in.	..	5,400	6,900	8,300	10,800	8,300	10,300	860
3–6 in.	..	1,700	2,100	2,300	1,700	1,500	1,200	270
6–9 in.	..	900	1,000	800	800	700	600	200
Percentage of organic carbon								
Munslow								
0–3 in.	3·1	3·5	3·8	3·7	3·9	3·7	3·7	0·2
3–6 in.	3·1	3·3	3·3	3·1	3·0	3·1	2·9	0·2
6–9 in.	2·1	2·3	2·2	2·0	2·0	1·8	1·7	0·2
Talgarth								
0–3 in.	1·7	1·9	2·6	2·4	2·3	2·0	2·5	0·1
3–6 in.	1·8	1·8	2·1	1·8	1·7	1·8	1·7	0·1
6–9 in.	1·5	1·6	1·6	1·3	1·2	1·3	1·4	0·1
Percentage of water-stable aggregates								
Munslow								
0–3 in.	58	81	74	85	85	79	82	5
3–6 in.	57	80	76	81	85	79	83	7
6–9 in.	66	78	70	82	84	75	82	5
Talgarth								
0–3 in.	30	52	66	73	80	75	75	5
3–6 in.	26	46	60	65	78	72	69	5
6–9 in.	26	34	45	50	66	54	59	6
Number of tillers/sq. ft.								
Munslow								
Total	..	534	601	545	530	507	507	52
Talgarth								
Total	..	510	419	538	534	516	505	46

* Least significant difference at $P = 0{\cdot}05$.

As with root weight, the highest proportion of organic carbon occurred in the upper soil layer (Table 3), and this was where the greatest changes with time took place. During the first two to three years the percentage in the upper soil layer increased and then varied around this figure. In the lower layers the percentage also increased during the first two to three years but then decreased.

The percentage of water-stable aggregates was low in the seedling year but increased with each succeeding year until the fifth harvest year. The increase was almost the same in all three layers at Munslow,

but was more marked in the upper layers than in the 6–9-in. layer at Talgarth.

Botanical Composition of the Sward

The botanical composition of the sward did not have such a great influence on the measurements as might have been expected (Table 4).

TABLE 4. *Effect of the Botanical Composition of the Sward on the Magnitudes of the Measurements*

Aberystwyth and Manorbier, 1952–3; Talgarth and Munslow, 1952–7

	Modified Cockle Park mixture	*Lolium perenne*	*Festuca pratensis*	*Phleum pratense*	*Dactylis glomerata*	*L.S.D.*•
Root weight (lb./acre)						
Aberystwyth	16,000	14,200	14,400	13,700	13,400	2,170
Munslow	12,700	13,200	11,400	9,900	10,100	1,060
Talgarth	12,100	12,000	10,200	10,500	9,900	1,100
Manorbier	7,400	7,100	7,900	6,800	5,200	680
Mean	12,100	11,600	11,000	10,200	9,700	..
Percentage of organic carbon						
Aberystwyth	3·7	3·9	3·8	3·7	3·6	N.S.
Munslow	2·9	2·9	2·9	2·8	2·8	N.S.
Talgarth	1·8	1·9	1·8	1·7	1·8	0·2
Manorbier	1·9	2·0	2·0	1·9	1·9	N.S.
Mean	2·6	2·7	2·6	2·5	2·5	..
Percentage of water-stable aggregates						
Aberystwyth	77	78	77	78	76	N.S.
Munslow	78	76	77	77	78	N.S.
Talgarth	57	58	57	56	58	N.S.
Manorbier	46	46	44	44	41	N.S.
Mean	65	65	64	64	63	..
Total number of tillers per square foot						
Aberystwyth	421	508	414	393	386	N.S.
Munslow	554	621	507	517	444	47
Talgarth	497	548	521	468	478	49
Manorbier	327	461	347	299	262	33
Mean	449	543	456	418	391	..

• Least significant difference at $P = 0{\cdot}05$.

At three farms out of the four the sward produced by the modified Cockle Park seeds mixture, which was composed mainly of *Lolium perenne*, produced the greatest weight of roots and the *Dactylis glomerata* the least. The *Lolium perenne* swards gave a similar weight of roots to the mixture, except at Aberystwyth. The *Festuca pratensis* and *Phleum pratense* swards were intermediate in root weight.

The swards varied little in the distribution of the root weight between the soil layers. *Phleum pratense* had a very slightly higher percentage in the 0–3-in. layer than the other swards (Table 5).

Except in the sward produced by the mixture, the number of tillers per unit area varied in almost the same manner as root weight, *Lolium perenne* producing most and *Dactylis glomerata* least. The swards produced by the mixture, although of similar botanical composition to the *Lolium perenne* swards, were considerably less dense. Both swards, however, produced almost the same weight of roots.

The percentages of organic carbon and water-stable aggregates in the soil were only slightly affected by the botanical composition of the swards (Table 4).

The interaction years × botanical composition did not give a significant 'F' test for any of the measurements, indicating that the differences between the swards did not alter in any consistent fashion with succeeding years.

TABLE 5. *Percentage of the Root Weight in each Soil Layer*

Calculated from Aberystwyth and Manorbier, 1952–3; and from Talgarth and Munslow, 1952–7

Soil layer	*Mixture*	*Lolium perenne*	*Festuca pratensis*	*Phleum pratense*	*Dactylis glomerata*
0–3 in.	73	72	71	75	71
3–6 in.	20	21	21	19	22
6–9 in.	7	7	8	6	7

Discussion

The measurements varied greatly with the year in which they were made. In comparing measurements made on the same sward in successive years, two factors have to be taken into account, the change in the age of the sward and the variation in the environment (principally the weather) from year to year. During the first year when the quantity of roots would depend entirely upon the extent of their growth, the weight increased from nothing to several thousand pounds per acre. As some of the roots, if not all, live for only a year [2], the weight after the seeding year would depend upon the balance between the growth of the new and the decay of the old. There was a tendency for the weight to increase with the age of the sward, i.e. for growth to be greater than decay, but it was by no means regular, as was shown by the decrease between 1955 and 1956.

As the sward aged, the percentage root weight in the upper 3 inches of the soil increased, while the percentage in the lower layers decreased (Table 6). This trend was not noted in the same years in trials from which the age of the sward had been eliminated as a variable [10], so it would seem that this change in the vertical distribution of the roots was the direct result of an increase in the age of the sward. A similar trend has been noted by other workers. Goedewaagen and Schuurman [11] suggested that it was due to defoliation of the ley by cutting or grazing, as this has been shown to have a similar effect. Differences in defoliation intensity in the field, however, have not been observed to influence root distribution [10]. Another reason that may be advanced to explain

this increased concentration in the upper layers is that the soil became more compact as the sward aged. Compaction may have acted in two ways. If the weight of roots per unit weight of soil remained constant, then the weight of roots per volume of soil would increase, as indeed it did. Alternatively, the roots may have been forced to grow nearer the surface to obtain sufficient oxygen. This lack of aeration, by restricting the growth of the plant as a whole, would account for the decrease in herbage yield which has been stated to occur as the sward ages [12, 13].

TABLE 6. *Percentage of Root Weight in each Soil Layer*

Mean of Talgarth and Munslow

Soil layer	*1952*	*1953*	*1954*	*1955*	*1956*	*1957*
0–3 in.	68	70	73	79	79	82
3–6 in.	23	21	19	15	15	14
6–9 in.	9	9	8	6	6	4

TABLE 7. *Percentage of Organic Carbon in the Soil at Aberystwyth*

	1951	*1952*	*1953*	*L.S.D.*•
0–3 in.	5·0	4·7	4·9	N.S.
3–6 in.	4·2	4·3	3·6	0·3
6–9 in.	4·0	2·7	2·5	0·2

• Least significant difference at $P = 0{\cdot}05$.

The percentage of organic matter in the soil is also dependent upon a balance between two processes: the decay of grass roots, leaves, animal excreta, &c., and the mineralization of the organic matter that forms an integral part of the soil. It was the upper layer of the soil that contained most of the roots and so would receive most 'new' organic matter from this source, as well as from animal excreta and dead leaves. The increase in organic matter in the upper layer of the soil indicates that there was more added to the soil than was lost by mineralization.

In the lower soil layers there was a net loss in organic matter over the experimental period. During the first few years the amount of fresh organic matter more than counterbalanced the loss from mineralization, but as the sward aged and the percentage of root weight in the lower layers decreased, the addition of fresh organic matter was insufficient to make good the loss from mineralization. This loss was very marked at Aberystwyth (Table 7) where a large quantity of organic matter was no doubt added to the soil when the sward of the permanent grassland was ploughed up a year prior to the experiment. Even in the upper layer the large amount of organic matter added just balanced the loss through mineralization.

These results illustrate the differences between arable fields in which cultivation makes the soil uniform to the depth of ploughing (as these soils were at the beginning of the experiment) and grass fields in which soil conditions change progressively with increasing depth.

As water-stable aggregates are largely the outcome of the joint action of grass roots and soil organic matter, it is not surprising that the percentage increased with each succeeding year, and that the increase was greater in the upper than the lower layers.

The differences in root weight under swards of different botanical composition may have been due to variations in the amount of roots produced, or to variations in the rates of decay of the old roots. In the 'one-grass' swards the variation in the number of tillers in the same manner as the root weight suggests that the root weight may merely be a reflection of plant density. In pot experiments with young plants it was found that the weight of roots per pot increased with plant density, although the individual plants became smaller [14]. The finding of the same (or slightly higher) weight of roots under the Cockle Park mixture and *Lolium perenne* swards when the former was much less dense than the latter is difficult to explain. Both had about the same botanical composition.

The percentages of organic carbon do not show such large differences as root weight although there is some indication that the higher root weight of *Lolium perenne* was associated with a slightly higher percentage.

In other investigations there is considerable variation in the degree of correlation found between the quantity of roots produced by swards of different botanical composition and the degree of soil aggregation. In the present investigation the degree of aggregation was the same under all swards, although the root weight varied considerably, i.e. there was no correlation. This is in agreement with the results of Barley [15]. Ward [16] reported low positive correlation while Williams [17] reported a close relationship. The author [2] concluded that grass roots were associated in two ways in the formation of soil aggregates: they had a direct effect on the soil by mechanically holding soil particles and small aggregates together, and they provided food material for micro-organisms producing substances which cemented soil particles together to form aggregates.

Robinson and Jacques [18] found a significant correlation between the weight of grass roots and the degree of aggregation 4 months after sowing, but not at later dates. Thus a correlation occurred prior to the decay of any large quantity of organic matter produced by the plant, i.e. before food was available for the micro-organisms producing the cementing compounds. It seems a reasonable assumption that where the aggregates are held together by the direct mechanical action of the grass roots, a positive correlation between the weight of roots and the degree of aggregation would be found. If, however, the direct action of the grass roots only played a small part, and the aggregates were held together largely by the microbial cements, no correlation would be expected. On this basis aggregation under the conditions of the present experiment was due to microbial activity rather than to the direct physical influence of the roots.

The possible effect of the farmers' management practices upon these measurements has not been considered in this paper, because all the fields, with the exception of Munslow in some years, were cut for hay

and the aftermath grazed. Also in a large experiment at Aberystwyth [10] it was found that within the limits of agricultural practice widely differing grazing and cutting treatments had only small influences on the magnitudes of the measurements.

Acknowledgements. The author thanks Professor P. T. Thomas, present Director of the Welsh Plant Breeding Station, and Professor E. T. Jones, former Director, for facilities to carry out this work, also Mr. Ll. I. Jones together with other members of the Grassland Agronomy Section for help and advice. Acknowledgement is made to Dr. Rice Williams, N.A.A.S. (Wales), for analyses of the soil; the Department of Statistics, Rothamsted Experimental Station, for considerable help in the analysis of the results, and Messrs. Dorman Long & Co. Ltd., for making the soil samplers. Without the co-operation of the farmers on whose land the experiments were conducted, this work would not have been possible, and the writer expresses his appreciation of their help.

REFERENCES

1. R. M. Langer, *Ann. Appl. Biol.*, 1956, **44**, 166.
2. A. Troughton, *Comm. Bur. Pastures & Field Crops*, Bull. 44, 1957, p. 163.
3. G. V. Jacks, *Imperial Agricultural Bureau Joint Publication*, No. 6, 1944, p. 42.
4. A. Troughton, *J. Brit. Grassl. Soc.*, 1951, **6**, 197.
5. A. J. Low, *J. Soil Sci.*, 1955, **6**, 179.
6. A. Walkley and I. A. Black, *Soil Sci.*, 1934, **37**, 29.
7. E. W. Russell and R. V. Tamhane, *J. Agric. Sci.*, 1940, **30**, 210.
8. Anon., *Climatological Atlas of the British Isles*, London, Meteorological Office, H.M.S.O., p. 139, 1952.
9. Anon., *British Rainfall*, London Meteorological Office, British Rainfall Organisation, H.M.S.O., 1951, 1952, 1953.
10. A. Troughton, Thesis, Univ. Wales, 1958.
11. M. A. J. Goedewaagen and J. J. Schuurman, *Trans. IV. Internat. Congr. Soil Sci. Amsterdam*, 1950, **2**, 28.
12. R. Pollitt, *J. Brit. Grassl. Soc.*, 1947, **2**, 119.
13. R. Paterson, *Sixteen Years of Grassland Recording on a Farm Scale*, in *The Measurement of Grassland Productivity*, ed. J. D. Ivins, London, 1959, p. 194.
14. A. Troughton, *J. Brit. Grassl. Soc.*, 1956, **11**, 56.
15. K. P. Barley, *Aust. J. Agric. Res.*, 1953, **4**, 283.
16. H. S. Ward (Jr.), *Ecol. Monogr.*, 1949, **19**, 145.
17. T. E. Williams, *The Ley in Relation to Crop Productivity*, in *The Measurement of Grassland Productivity*, ed. J. D. Ivins, London, 1959, p. 15.
18. G. S. Robinson and W. A. Jacques, *N.Z. J. Agric. Res.*, 1958, **1**, 199.

(*Received 3 May 1960*)

AN EXPERIMENTAL STUDY OF *STOEBE VULGARIS* IN RELATION TO GRAZING AND BURNING

IRENA KRUPKO AND R. L. DAVIDSON

(*Frankenwald Field Research Station, University of the Witwatersrand, Johannesburg*)

WITH PLATES 7, 8, 9

Summary

The experiments described are part of a long-term study of the ecology of *Stoebe vulgaris*, a bushy ericoid perennial weed in South African pastures, which has increased on the sandy soils of the Highveld, where burning and heavy grazing have been discouraged over the past twenty-five years. The experiments have shown that the establishment of Stoebe can be prevented by spring burning of grassland, which otherwise becomes heavily infested. Once established, Stoebe is not killed by spring burning, but over a period of ten to fifteen years annual burning at this time of year leads to a gradual reduction of Stoebe. It is presumed that this results from the senescence of established plants and the prevention of ecesis of seedlings by fire.

Heavy grazing without burning has reduced the amount of Stoebe, and heavy grazing together with burning have eliminated it. Both these treatments have led to changes in grass species similar to the botanical changes resulting from the application of nitrogen and phosphorus in this region.

The eradication of Stoebe with sodium chlorate and by hoeing was found to be temporarily effective. The reinvasion of these plots by Stoebe where fire has been withheld has shown clearly that on certain soils carrying natural grassland the encroachment of Stoebe is not caused by overgrazing or fire. It is clear that chemical or mechanical means of control are not effective unless they are followed by burning or heavy grazing.

THE problem of *Stoebe vulgaris* Levyns (bankrupt bush) in pasture has been studied at Frankenwald by many students since 1932, under the direction of Professor John Phillips, notably Gillman [1], Cohen [2, 3, 4], and van Rensburg [5]. This earlier work is reviewed by Hattingh [6], who describes the distribution of *Stoebe vulgaris* in South Africa. This plant is a grey, low-growing erocoid bush occurring mainly on the sandy soils of the Highveld with an annual rainfall of about 30 inches, but it is also more sparsely distributed over a very much wider area. Infestation of grassland with Stoebe presents a serious problem on the sandy soils, both in the grassland subclimax of Trachypogon, other species, and in seral grassland on old fallows dominated by species of Eragrostis and *Hyparrhenia hirta*. Previously it was thought that bankrupt bush encroachment was the result of overgrazing, but this is questioned by Hattingh on the basis of long-term experiments at Frankenwald. These experiments have now been maintained since 1937, and the present paper is an account of this experimental study of *Stoebe vulgaris* in relation to burning and grazing. The conclusions drawn from this work are very different from those reached earlier.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

The hypothesis now advanced suggests that the encroachment of bankrupt bush upon the grassland of the sandy soils of the Highveld has resulted in part from a decrease in the frequency of veld fires over the past twenty-five years, and in part from too little grazing by stock. The natural grassland of the region is a biotic subclimax community maintained by fire and grazing, in which, when it is protected for several years, the vigour of the grasses declines. Under these conditions unpalatable species increase markedly in the grassland, forming rank patches which are avoided by stock so long as other grazing is available. Consequently, there is little return of dung and urine to the soil, so that fertility declines. It is suggested further that Stoebe seedlings are killed by fire, to which older plants are resistant.

Experimental Procedure

In 1937 two experimental blocks U_3 and U_5 were set out in Trachypogon and other species grassland on sandy soils derived from pre-Witwatersrand old granites. Each block consists of nine plots 20 yards square, to which the following treatments have been applied:

Plot 1. Burned annually in August and grazed heavily (i.e. ten to fifteen cattle for one half-day weekly or monthly according to season).
2. Stoebe poisoned with sodium chlorate in 1938, and burned annually in August; lightly grazed.
3. Stoebe hoed out in 1937 and 1940; lightly grazed.
4. Stoebe poisoned with sodium chlorate in 1937, 1938, and 1940; lightly grazed.
5. Complete protection from burning and grazing.
6. Burned annually in August; not grazed.
7. Grazed heavily (i.e. ten to fifteen cattle one half-day weekly or monthly according to season).
8. Burned annually in August; lightly grazed.
9. Stoebe hoed out in 1937 and 1940; lightly grazed.

In addition, grass seed was scattered in plots 2, 3, 4, 8, and 9 but none of the sown grasses established themselves. Plots 2, 8, and 9 were lightly cultivated with a spike roller in 1939, but this treatment had no noticeable effect. With minor exceptions the treatments prescribed were carried out until the summer of 1952/3, after which they were discontinued for two years, and then resumed except that the grazing treatments were omitted.

Botanical analyses were carried out in 1937, 1941, and 1954 in Block U_3, and in 1939, 1941, and 1954 in Block U_5. Four quarter-square-metre (50×50 cm.) permanent quadrats were set out in each plot, in which the basal cover of all species was listed. These quadrats provided a reliable measure of the grass cover, but they were too small to measure the incidence of Stoebe. In 1954 and again in 1959 the Stoebe plants in each plot were counted. It is sometimes difficult to decide where one plant begins and ends; the counts therefore should be taken as a relative measure of abundance. In U_3 the approximate number of Stoebe plants was estimated in 1937.

TABLE 1. *Percentage Basal Cover in Blocks U_3 and U_5; means of eight quarter-square-metre Quadrats per Treatment*

	1937/9	1941	1954
Plot 1			
subclimax	6·06	4·54	0·93
seral	5·66	6·70	9·83
Stoebe	3·38	2·42	0
Total cover	15·10	13·66	10·76
Plot 2			
subclimax	8·58	8·41	3·66
seral	4·52	5·35	6·38
Stoebe	1·10	0	0
Total cover	14·20	13·76	10·04
Plot 3			
subclimax	12·46	9·91	0·75
seral	2·10	3·55	2·14
Stoebe	0·58	0·07	0·80
Total cover	15·14	13·53	3·69
Plot 4			
subclimax	5·17	6·58	1·54
seral	5·72	4·21	1·27
Stoebe	0·66	0·09	0·74
Total cover	11·55	10·88	3·55
Plot 5			
subclimax	5·88	7·90	2·95
seral	6·92	4·33	0·75
Stoebe	0·30	0·68	1·16
Total cover	13·10	12·91	4·86
Plot 6			
subclimax	7·94	8·95	6·02
seral	5·07	4·75	1·56
Stoebe	1·09	0·98	1·16
Total cover	14·10	14·68	8·74
Plot 7			
subclimax	2·68	2·45	1·16
seral	8·30	11·63	11·93
Stoebe	0·23	0·59	0
Total cover	12·45	16·54	13·09
Plot 8			
subclimax	4·89	6·03	6·38
seral	7·25	7·15	4·38
Stoebe	0·08	0·26	0
Total cover	12·22	13·44	10·76
Plot 9			
subclimax	2·51	6·03	2·73
seral	7·29	6·41	1·78
Stoebe	0·27	0·02	0·86
Total cover	10·07	12·46	5·37

Block U_5 is situated on poorly drained soil with less vigorous grassland than Block U_3, but both blocks show the same trends. Table 1 shows the mean percentage basal cover of the vegetation at the different dates. The species present are divided into (*a*) the subclimax species

comprising an association, typical of undisturbed areas, dominated by *Trachypogon spicatus*, *Tristachya hispida*, and *Elyonurus argenteus*; (*b*) the species belonging to seral stages earlier in the succession, mainly *Cynodon dactylon* and *Eragrostis curvula*; and (*c*) *Stoebe vulgaris*.

From Table 1 it will be seen that in the protected, or unburnt and lightly grazed plots 3, 4, 5, and 9 in which Stoebe is abundant (see below), there was a marked decrease in the basal cover of grasses. This is ascribed to the shading effect of the large Stoebe bushes in these plots. In the burnt plots 2, 6, and 8, there has been a slight decrease in total cover of grasses, but the proportion of subclimax species has increased. In the heavily grazed plots 1 and 7 the seral grasses have increased from about a third to about nine-tenths of the total cover. This effect is

TABLE 2. *Approximate Number of Stoebe Plants per Plot*

	Block U_3			*Block* U_5	
Plot	*1937*	*1954*	*1959*	*1954*	*1959*
1	120	0	0	115	76
2	135	2	0	282	128
3	100	1,912	852	1,196	750
4	80	1,381	647	1,144	786
5	80	835	619	536	514
6	100	390	215	456	359
7	90	47	212	110	143
8	70	310	74	322	308
9	100	1,503	760	1,035	503

similar to that of nitrogenous fertilizer on subclimax grassland in other experiments at Frankenwald [7], and it is thought to be due to the addition of plant nutrients by the animals, in the form of dung and urine.

The approximate number of Stoebe plants in each plot is given in Table 2; in the burned plots the plants in strips along the fences which were not fired are not included.

In the protected plots (5) there has been a rapid increase in the amount of Stoebe, and today they are overgrown with the weed (Fig. 1, Plate 7). There appears to have been an increase in the size and number of plants, and the grasses have been drastically reduced by the rank growth of Stoebe. A few old Stoebe plants have died, but they are being replaced by seedlings of the same species. Clearly protection is not a method of control, even after twenty-two years.

The plots 3 and 9, in which Stoebe was hoed out in 1937 and again in 1940, were virtually free of the weed in 1941. This was judged then to be the most effective treatment. Today these plots in both U_3 and U_5 have more Stoebe plants than any others. This shows that environmental conditions were suitable for the reinvasion of Stoebe, although there was a vigorous growth of Monocymbium, Eragrostis, and other grasses after the poisoning (Figs. 2 and 3, Plate 7).

A similar history is seen in plot 4 in which the Stoebe was sprayed with sodium chlorate in 1937, 1938, and 1940. Most of the Stoebe plants were dead in 1941, and the grass surrounding then (which had

also been harmed by the poison) was vigorous again. This treatment was judged to be effective, but too expensive for use on a large scale. Stoebe has reinvaded these plots, and there are now more plants than ever before.

In plot 2 the Stoebe plants were sprayed only once with sodium chlorate, in 1937, and subsequently the grassland was burned annually in August. In this treatment there were still a few Stoebe plants in 1941, but there are now no plants in the plots of this treatment in U_3 and only 128 plants in U_5. Fire appears to have prevented re-entry of Stoebe.

The effect of burning the grassland in August without any other treatment is seen in plots 6 and 8. These have comparatively little Stoebe, and the shoots are small and do not overshadow the grasses. Most of the Stoebe plants are old, and many individuals appear to be remnants of plants of which the main rootstocks have died. For this reason what was probably one plant is now being counted as several plants. In 1941 Stoebe was abundant in these plots, which showed no effect after four years of burning. Since then there appears to have been a gradual decrease in the number of plants, suggesting the death of old plants without the establishment of new ones. Stoebe seedlings at the end of one growing season are only a few inches high, and the hypothesis being examined is that they are not resistant to fire at this age. The effects of treatments 2, 6, and 8 suggest that burning in August prevents the establishment of Stoebe in undisturbed grassland. Smit [8] has shown that burning in winter and early spring does not prevent the establishment of Stoebe on poor fallow land, but burning in November and December prevents establishment and also kills mature Stoebe plants.

The 'heavily grazed' treatments, in which cattle were held one half-day weekly or monthly according to season, were originally set out in the expectation that Stoebe would increase under this treatment. However, these plots have shown the most effective eradication of Stoebe in the whole experiment. Where burning has been combined with heavy grazing the results have been most striking. In U_3 plot 1 (burned and grazed) there are no Stoebe plants; in U_3 plot 7 (grazed only) there were 47 plants in 1954, and since grazing has been withheld the number has increased to 212. The contrasts between these two treatments in 1940 and 1959 are shown in Figs. 4–7, Plates 8 and 9. At the commencement of the experiment these plots had a dense stand of Stoebe. In U_5 these treatments also had the lowest number of Stoebe plants in 1954, and again the number of plants in plot 7 has increased since grazing was stopped in 1952. The change in species-composition of the grassland and the vigorous growth of grass suggest that the plant nutrients brought in through the dung and urine of the grazing animals have increased the fertility of the soil. It should not be concluded that the same results will be achieved in a self-contained grazing unit, except in so far as the animals return the greater part of the nitrogen intake of protein, and concentrate it on a relatively small area. The effect of trampling *per se* requires further investigation.

Conclusions

1. Poisoning and hoeing have no more than a temporary effect on Stoebe infestation, unless conditions are made unsuitable for reinvasion.

2. Burning in August in this veld type (*Trachypogon* and other species grassland) has prevented reinvasion after eradication by hoeing or poisoning, and appears gradually to have reduced Stoebe infestation by preventing ecesis as older plants died. It is suggested that the general reduction of veld burning in the Highveld during the past twenty years is partly responsible for the increase in *Stoebe vulgaris* in the grassland subclimax in this region.

3. While the effects of heavy grazing are difficult to interpret in ecological terms, it is clear that heavy grazing cannot be the cause of Stoebe encroachment in the Highveld. On the contrary it would appear that heavy stocking (with the accompanying return of nutrients in excreta) may reduce the infestation of Stoebe as well as prevent its encroachment.

4. Protection is not effective either in eradicating Stoebe or in preventing its re-establishment once it has been removed. Furthermore, where fire and grazing are withheld Stoebe has increased to form a consociation from which grasses are virtually excluded on soils which are typical of this region of the Highveld and have not been ploughed in the past.

5. This investigation has shown the value of long-term research on problems of bio-ecology, and it illustrates the need for integrated plant-animal ecological research in South Africa. Botanical research in which animal factors are not quantitatively defined will lead to vagueness and confusion.

Acknowledgements. The experiments under discussion were set out by Mr. H. Janse van Rensburg under the direction of Professor John Phillips, formerly Head of the Department of Botany. Thanks are due to the many postgraduate students who have worked on the experiment during past years.

The Department of Agriculture in the Union of South Africa is thanked for financial assistance given towards this investigation.

REFERENCES

1. H. Gillman, *Stoebe cinerea*, M.Sc. thesis, Witwatersrand University, 1934.
2. C. Cohen, *J. S. Afric. Bot.*, 1935, **1**, 171; 1940, **6**, 79.
3. —— *S. Afric. J. Sci.*, 1936, **33**, 351.
4. —— *Stoebe vulgaris* Levyns, M.Sc. thesis, Witwatersrand University, 1940.
5. H. J. van Rensburg, *S. Afric. J. Sci.*, 1940, **37**, 175.
6. E. R. Hattingh, *Empire J. Expt. Agric.*, 1953, **21**, 309.
7. T. D. Hall, D. Meredith, and R. E. Altona, ibid., 1950, **18**, 8.
8. I. B. J. Smit, *The Effect of Veld Burning on* Stoebe vulgaris, B.Sc. Honours thesis, Witwatersrand University, 1954.

(*Received 16 April 1960*)

FIG. 1. Control Plot 5 in U_3 after 23 years' protection from fire and grazing, except for an accidental burn in 1939.

FIG. 2. Plot 4 in 1940, showing vigorous grassland after Stoebe had been poisoned three times with sodium chlorate and lightly grazed.

FIG. 3. The same plot as shown in Fig. 2 in 1959 after protection from fire since 1937, and protection from grazing since 1943, showing reinvasion by Stoebe. There was no Stoebe in this plot in 1941.

FIG. 4. Photograph taken in 1940 showing plot 1 on the right (with Stoebe still present in heavily grazed burned treatment) and plot 2 on left (poisoned with sodium chlorate and burned in August).

FIG. 5. The same plots as shown in Fig. 4, both plots in 1959 being completely free of Stoebe.

FIG. 6. Photograph taken in 1940 showing plot 7 on the right (with abundant Stoebe in heavily grazed grassland) and plot 8 on the left (burned annually in August).

FIG. 7. The same plots as shown in Fig. 6 photographed again in 1959. Plot 7 on the right has vigorous seral grassland with only a few old Stoebe plants and many small Stoebe seedlings which have invaded the plot since grazing was discontinued in 1952.

THIRTY LONG-TERM FERTILIZER EXPERIMENTS UNDER CONTINUOUS CROPPING IN GHANA

I. CROP YIELDS AND RESPONSES TO FERTILIZERS AND MANURES

R. K. DJOKOTO AND D. STEPHENS[1]

(*Department of Agriculture, Ghana*)

Summary

Thirty fertilizer trials of factorial design have been continued for between three and nine years. In spite of some imperfections, the experiments have in most cases elucidated the main nutrient requirements of the different crops at the different centres.

In the forest zone the primary need was phosphorus, followed by potassium. In Ashanti, and at the long-rest savannah sites, nitrogen was the first requirement, followed by phosphorus. In the north phosphorus and nitrogen were first needed, and later lime.

The organic treatments have nearly always given better results than the inorganic fertilizers, especially after some years of cropping; the greater part of their action seems to be due to their nutrient content, but a residue of unexplained benefit remains which is probably connected with the balanced nutrient reserves slowly released during the crops' growth by the decomposition of organic matter, and, in the case of mulch, with the improved rain acceptance and slower drying out of the top soil.

Soil studies, in relation to the yield responses to fertilizers and manures here reported, will be dealt with in Part II.

IN 1948 and 1949 a number of fertilizer trials of identical 2^5 factorial design were laid down at agricultural stations throughout the Gold Coast to determine the main plant nutrient deficiencies in the country [1]. Many of them were discontinued after one or two years when this general survey had been completed. Some, however, were continued, in order to follow the nutrient status of the soils under continuous cropping, and to determine the effects of regular application of different fertilizers. After 1950 a few inconveniently sited trials were given up, and others were started; by 1957 there were in all thirty of these experiments, at twelve stations, which had continued for between three and nine years. This paper summarizes the results of this series of experiments up to the end of the 1956/7 cropping year.

Sites and Rotations

For the locations of the sites in relation to the main vegetational [2] and geological [3] zones, reference should be made to the maps in earlier papers [4, 5]. Additional information is given below. Unless otherwise mentioned, sites were on middle or upper slopes with free drainage;

[1] Present address: Kawanda Research Station, P.O. Box 265, Kampala, Uganda.

[Empire Journ. of Exper. Agric., Vol. 29, No. 114, 1961.]

3988.114 N

Munsell colour codes refer to air-dry soil. Yams were nearly always grown on mounds and all other crops on ridges.

Aiyinasi. In the rain forest zone. Mean annual rainfall 96 in. (based on four years' records only) with peaks in June and October and no pronounced dry season. Two trials were started in 1949, on soils of the Basachia series [6], with greyish-brown gravelly sandy loam top soils, developed over unconsolidated tertiary deposits and usually a ferruginized layer at about 2 ft. The land had probably been under secondary forest for about ten years before clearing in 1948. A two-year rotation was used; first year: maize followed by groundnuts; second year: cassava. In each year the two trials carried different courses of the rotation.

Kwadaso. Moist semi-deciduous forest. Rainfall 61 in., and bimodal like Aiyinasi. Four trials were started in 1949: two on soils over granite, with grey-brown (10YR/5/2) gravelly sandy loam top soil, and a permeable layer of quartz and ironstone at about 3 ft.; and two over lower Birrimian phyllite within the metamorphic aureole of the granite, with reddish-brown (5YR/4/3) gravelly clayey loam top soils, and a layer of ironstone and quartz gravel at about 2 ft. All sites had been under secondary forest bush for about three years after being used by local farmers; the granite sites were cleared in 1948 and the phyllite early in 1949. Until 1953 the rotation was, first year: maize followed by cassava; second year: cassava continuing. To reduce tuber rot in the cassava, due to *Fomes* sp., after 1953 the rotation was extended three years, first year: maize followed by groundnuts; second year: maize followed by cassava; third year: cassava continuing. In pairs of trials each carried a different course of the rotation.

Mampong. Dry semi-deciduous forest. Rainfall 55 in., bimodal. One trial was started in 1949, over Upper Voltaian (V3) sandstone, with top soils of dark-brown medium sands, and a layer of ironstone and quartz gravel at 3–4 ft. Previously the land had been under a rotation of approximately three years' cropping and three years' rest. The trial rotation was the same as at Kwadaso.

Wenchi. Dry semi-deciduous forest grading into Guinea savannah woodland. Rainfall 51 in., bimodal. Two trials were started in 1953, over Voltaian (V2) sandstones of the Obossum beds, with top soils of brown sands, overlying an ironstone pan at about 2 ft. Previously under savannah bush. Trial 1 was cropped with yams, maize, groundnuts, and cassava; and trial 2 with maize followed by two groundnut crops, then cassava.

Ejura. Guinea savannah woodland. Rainfall 55 in., bimodal, with a severe dry season in December and January. Two trials ran from 1948 to 1952, two more were started in 1953 and another in 1954. Dark-brown (7·5YR/4/4) medium sandy top soils, developed over Voltaian (V2) sandstone, with ironstone at about 3 ft. Before clearing all the sites had been under savannah bush (chiefly grasses) for many years. The rotation was variable, but usually followed the pattern—first year: yams; second year: maize followed by groundnuts; third year: one, or two, crops chosen from cassava, *Urena lobata*, tobacco, and groundnuts.

Tamale, Nyankpala, and Damongo. Guinea savannah woodland. Rainfall 42–45 in. with a single peak in September, and a severe dry season. At each station two trials were started in 1948–9, on soils developed over Voltaian sandstones, with brown (7·5YR/4/4–7·5YR/6/4) medium-fine sandy top soils, and a concretionary layer at 2–3 ft. The Tamale trials were on lower slopes. At Nyankpala another two trials were sited on lower slopes over Voltaian shales, with light yellowish-brown (10YR/6/4) fine silty sand top soils, overlying an ironstone pan sometimes coming to within 6 in. of the surface. At Damongo the land had been under bush for ten years or more before clearing for the trials, whereas at Tamale and Nyankpala it had been fairly frequently cropped. At Tamale and Nyankpala a three-year rotation was used: yams; maize and guineacorn; groundnuts. At Damongo a two-year rotation: maize and guineacorn; groundnuts.

Babile, Tono, Zuarungu, and Manga. Guinea savannah. Rainfall 40–43 in. with a severe dry season lasting from November to April. Each station had two trials, started at Babile in 1951 and at the other stations in 1948. All had light-brown (7·5YR/6/4 to 10YR/5/3) coarse, sandy gritty top soils, developed over granite, with a hard-pan of quartz and ironstone concretions at about 2 ft. at Babile, and at 2–5 ft. at Tono, Zuarungu, and Manga. All sites had been cropped for many years previously, and had received light dressings of kraal manure about every third year. At Babile the three-year rotation was: maize and guineacorn; millet; groundnuts; while at the other three stations it was: early millet and guineacorn; early and late millet; groundnuts.

Experimental

All trials were of standard 2^5 factorial design, with thirty-two 1/40-acre plots (1/80 acre in the three later trials at Ejura) in four blocks of eight.

In all trials the interactions NPK, PLM(D), and NKLM(D) were confounded with block differences.

After 1949 the standard treatments per acre were:

N = Ammonium sulphate (21 per cent. N), 120 lb. each season or year.
P = Single superphosphate (18 per cent. P_2O_5), 120 lb. each season or year.
K = Muriate of potash (60 per cent. K_2O), 60 lb. each season or year.
L = Quick lime (Buxton Temper Lime) at 5–10 cwt. about every four years.
M = Mulch at 5 tons dry grass each season or year.
D = Kraal manure at 2–4 tons each season or year.

At Kwadaso and Ejura the treatments were not applied to second-season groundnuts.

Mulch and kraal manure were alternatives. Manure was available only at the northern centres, where one trial of a pair had the mulch and the other the manure treatment. In 1948 and 1949 the fertilizer rates were higher than the above standards, viz. 240 lb./acre for all three

fertilizers (except for muriate of potash in 1949, when it was only 120 lb./acre). Furthermore, in 1948 all the trials had mulch treatments, none having kraal manure, and in 1949 most of the trials on the northern granitic sites had kraal manure instead of mulch; while in later years mulch and manure were occasionally applied to the wrong experiments. As a result nearly every trial at a centre where both mulch and manure were used had both treatments at least once, while at Manga and at Zuarungu the mulch trials had manure applications on two and on four occasions respectively.

Crop residues were normally cleared away and not ploughed in. Top growth was usually collected for livestock bedding or fodder shortly after harvest and any undecomposed stools, &c., were removed at the beginning of the next season when preparing the land for the new crop. At Kwadaso and Ejura, where there were no cattle, the trash was usually left on the plots until the following season.

Results and Discussion

Mean Yields and Effects at Each Site

Table 1 shows the mean yields, treatment main effects, and significant interactions for each crop, averaged at each type of site over all seasons.

Before discussing the results, three points must be mentioned. First, an epidemic of rust (*Puccinia polysora*) devastated the maize in southern Ghana in 1950 and spread with decreasing severity over most of the country in later years; this resulted in complete loss of the crop in the trials at Aiyinasi and Kwadaso in 1950, and in yields less than 400 lb. of grain per acre at Aiyinasi, Kwadaso, and Mampong in 1951.

Secondly, the estimates of error used for significance tests were obtained by taking the square root of the sum of the error variances of the individual trial crop yields and dividing by the number of trial crops; this eliminated treatment × season interactions from the estimates of error. It has been pointed out (A. J. Vernon, private communication) that it would be more correct to calculate the standard errors for each treatment effect separately, but this would involve more computation than facilities allowed, and was not attempted. The procedure adopted may give low estimates of error which exaggerate the apparent accuracy of the experiments. Furthermore, as twenty-eight treatment main effects and interactions were measured in each trial, the occurrence on the average of a few non-significant values at the $P = 0{\cdot}05$ level would be expected purely by chance.

The final row in Table 1 names the nutrient deficiencies which seem to be chiefly responsible for the effects obtained, and these are described below.

In the forest sites, at Aiyinasi and Kwadaso, the main deficiencies over the six years of continuous cropping have been of phosphorus and potassium. Mulching with grass increased yields of all crops, partly because it supplied potassium and, to a lesser extent, phosphorus. Maize lacked both nutrients, and showed the consequent response pattern of +P, +K, +M, +PK, −PM, −KM, and −PKM, while

TABLE 1. *Mean Yields, and Treatment Main Effects and Significant Interactions Expressed as a Percentage of Mean Yield, Averaged over all Seasons at each Station or Site*

At sites where one trial had mulch and the other had kraal manure, the number of seasons for each of these treatments was approximately half that quoted.

The dash — indicates kraal manure was not used at this station.
(n.a.) = result not available.

A. CEREALS

Site	*Aiyinasi*	*Kwadaso, Granite*	*Kwadaso, Phyllite*	*Mampong*	*Wenchi*	*Ejura*	*Tamale*	*Nyankpala, Sandstone*	*Nyankpala, Shale*	*Damongo*	*Babile*	*Tono*	*Zuarungu*	*Manga*
No. of trials	2	2	2	1	2	4	2	2	2	2	2	2	2	2
No. of seasons	7	10	9	6	4	8	8	6	7	8	8	12	12	12
Mean yield (lb./acre)	623	863	708	1430	821	1112	1194	1384	906	1211	957	665	609	838
Treatment effects as % of mean:														
N	1	−1	0	12	29	31	18	24	3	9	16	11	7	26
P	15	39	48	12	58	14	14	31	30	26	39	40	27	42
K	5	7	8	−1	22	3	3	4	−7	−1	2	4	−10	9
L	1	4	10	1	(n.a.)	1	6	12	13	−1	4	3	−3	3
M	11	36	34	24	20	3	16	21	32	21	35	50	(n.a.)	33
D	—	—	—	—	—	—	51	30	53	—	36	40	59	43
NP			−7		19		8	15		10		10	10	13
NK		7			19				−10		−6	−5	−12	
NL				9					9	6	−7			
NM									14		−10			8
ND	—	—	—	—	—	—			−18	—				−10
PK		15	10	−8	18									
PL									−9					
PM		−9					−11			−7		−9		
PD	—	—	—	—	—	—		−11	−18	—	8	−10	−21	−9
KL									8	9		5		
KM		−13	−11							−6	15			
KD	—	—	—	—	—	—			—	—		−8		
LM				−11				−8		−9				
LD	—	—	—	—	—	—	−17			—			−8	
NPL										9				6
NPM											−15			
NPD	—	—	—	—	—	—	−20 (*a*)			—				−13
NKM								13		6				
NKD	—	—	—	—	—	—	−17 (*a*)			—	9			−7
NLM				−10	(n.a.)							5		
NLD	—	—	—	—	—	—				—	9		11	
PKL				11					−11					
PKM		−8	−11		−14			−9						
PKD	—	—	—	—	—	—		12 (*a*)		—				
Least sig. diff. ($P = 0{\cdot}05$)	7	6	5	7	11	6	7	5	8	6	6	5	7	4
Least sig. diff.	For treatments with M only						6	7	12		10	7	(n.a.)	5
Least sig. diff.	For treatments with D only						12	9	12		8	7	10	7
Summary of deficiencies	P	P & K	P & K	P and N+L	N, P, & K	N & P	N & P	N, P, & L	P & L	P and N+L	N & P	N & P	N & P	N & P

(*a*) Owing to incomplete records of earlier years these second-order interactions are based on fewer seasons than the other effects.

TABLE 1 (*cont.*)

		B. CASSAVA						C. YAMS				
Site		*Aiyinasi*	*Kwadaso, Granite*	*Kwadaso, Phyllite*	*Mampong*	*Wenchi*	*Ejura*	*Wenchi*	*Ejura*	*Tamale*	*Nyankpala, Sandstone*	*Nyankpala, Shale*
No. of trials		2	2	2	1	1	1	1	4	2	2	2
No. of seasons		7	7	7	3	1	1	1	6	5	6	5
Mean yield (lb./acre)		12192	14461	11756	22464	26941	14213	17590	8797	5408	7351	5096
Treatment effects as % of mean:	N	−4	0	3	6	6	20	−2	8	3	−1	−14
	P	−2	0	8	1	12	−10	−3	6	7	10	15
	K	22	13	10	19	35	7	−10	−3	−2	0	−8
	L	4	0	−1	0	−4	16	(n.s.)	4	7	11	16
	M	28	25	26	34	66	−3	21	18	25	25	51
	D	—	—	—	—	—	—	—	—	32	14	38
	NK											−17
	NM	−8										9
	PK							17				
	PL		−6		−16							
	PM	−9										
	KL				8					12		
	KM	−9	−13	−13	−8	−20						
	NKL			13								
	NLM				−9							
	PKL				9							
	PKM								13			
Least sig. diff. ($P = 0.05$)		8	6	10	8	19	28	12	9	8	6	10
Least sig. diff.		For treatments with M only								9	10	8
Least sig. diff.		For treatments with D only								16	7	20
Summary of deficiencies		K	K	K	K	K	Perhaps N				P+L	P+L

TABLE I (*cont.*)

D. GROUNDNUTS

Site	*Aiyinasi*	*Kwadaso, Granite*	*Kwadaso, Phyllite*	*Mampong*	*Wenchi*	*Ejura*	*Ejura*	*Tamale*	*Nyankpala, Sandstone*	*Nyankpala, Shale*	*Damongo*	*Babile*	*Tono*	*Zuarungu*	*Manga*
No. of trials	2	2	2	1	2	2	4	2	2	2	2	2	2	2	2
No. of seasons	8	4	4	2	3	2	6	5	3	3	9	4	6	6	6
Mean yield (lb./acre)	682	596	461	1067	522	833	897	575	586	461	739	746	885	645	583
Treatment effects (*b*) as % of mean:	DIR	RES	RES	DIR	RES	DIR	RES	DIR	DIR	DIR	DIR	DIR	DIR	DIR	DIR
N	−3	−3	5	9	1	11	−8	−9	−11	−5	4	−16	−2	−4	−13
P	9	17	14	4	11	11	3	13	−3	7	21	24	21	9	36
K	5	−2	6	1	8	−6	−1	−7	2	−2	−1	−10	−4	−8	−2
L	8	2	−3	0	(n.a.)	10	5	22	16	21	6	10	6	1	10
M	3	10	10	70	8	23	5	14	−16	7	19	6	28	3	26
D	—	—	—	—	—	—	—	34	13	−4	—	10	14	18	16
NP												−7			8
NL								12			7	6			11
NM											−7				
PK					7		−4								−7
PL				13	(n.a.)						−10				−9
PM	−7			−17									−13		
PD	—	—	—	—	—	—	—				—	−10	−10	−11	
KL		10													
KM	−10											16			
KD	—	—	—	—	—	—	—				—	10			
LM													−12	−10	
LD	—	—	—	—	—	—	—				—	11			
NPM								−9				−13	11		
NKM									24			12		11	
NKD	—	—	—	—	—	—	—			23	—				
NLM	6			−15		−10									
KLD	—	—	—	—	—	—	—				—	−8			
Least sig. diff. ($P = 0{\cdot}05$)	6	10	8	10	6	9	4	7	11	15	5	6	6	6	7
Least sig. diff.	For treatments with M only							8	20	20		12	7	8	10
Least sig. diff.	For treatments with D only							10	12	20		6	9	9	8
Summary of deficiencies	P & L	P	P	P	P & K	N or S, P & L	L	P & L	L	L	P & L	P & L	P & L	P	P & L

(*b*) DIR = direct effects of treatments applied to the groundnuts. RES = residual effects of treatments applied to the crop preceding the groundnuts.

cassava required additional potassium only (hence the pattern +K, +M, and −KM), and groundnuts required only phosphorus (hence +P, +M, and to some extent −PM). Liming increased maize yields on the phyllite sites at Kwadaso and groundnut yields at Aiyinasi. Ammonium sulphate was quite ineffective. Yields and responses of maize were lower at the very wet station of Aiyinasi than at Kwadaso.

At Mampong nitrogen, phosphorus, and potassium deficiencies have developed and mulching was even more effective than farther south. Maize responded to superphosphate and to ammonium sulphate (especially in the presence of lime), but not to muriate of potash; lime interacted with other treatments to give a number of fairly large effects, which suggest that its action has been to counteract the effects of soil acidity brought about by repeated applications of ammonium sulphate and by continuous cropping without mulch. Cassava had the familiar pattern +K, +M, −KM; it also had a large negative value for the interaction PL and appreciable positive values for KL and PKL, which supports evidence mentioned later that superphosphate and lime intensify potassium deficiency. Groundnuts, surprisingly, have not responded significantly to superphosphate, but have the expected +M and −PM responses; the positive interaction +PL may mean that the availability of superphosphate in the rather acid soil (pH 5·6) was low and was increased by lime. For all crops the high-order interaction NLM was significantly negative which again points to the harmful acidifying action of repeated doses of ammonium sulphate, which can be remedied by either lime or mulch.

The Wenchi sites had only been cropped since 1953 but were already severely short of nitrogen, phosphorus, and potassium. All three deficiencies affected cereals, while groundnuts lacked phosphorus and potassium, and cassava only potassium; the single crop of yams was benefited by none of the inorganic fertilizers, but the significant positive interaction between P and K suggests that a balanced supply of these might have been beneficial. Lime was not applied until 1955 but it is most unlikely that it could have improved the yields of any crops except possibly yams. Mulch increased yields of all crops, being especially effective on cassava; the absence of significant negative interactions with P and K on cereals may be explained by the operation of additional positive interactions P×(K in mulch) and K×(P in mulch).

At Ejura, in the Ashanti Voltaian savannah, nitrogen especially, and phosphorus, were required by maize. Groundnuts responded only to direct applications of superphosphate, and to lime and mulch; the positive response to direct applications of ammonium sulphate was probably due to a shortage of sulphur on these two earlier sites [1, 5], whilst the residual negative responses in the later trials are to be expected when sulphur is not deficient. Yams responded to mulch only, and the single crop of cassava was not significantly affected by treatments. There have thus been no signs of potassium deficiency yet, although it is possible that further crops of cassava, which seems to be the best indicator, may show that it occurs.

The eight sites in the northern part of the Voltaian Guinea savannah (*Damongo*, *Tamale*, and *Nyankpala*) showed cereal responses which conform to the general pattern of +N, +P, +L, +M, +D, +NP, −PM, −PD, and −LM. The main requirements were, therefore, nitrogen, phosphorus, and a higher soil pH or more calcium; the organic manures supplied phosphorus, and mulching seems also to have counteracted the effects of a too low pH, while kraal manure may have acted similarly at Tamale and have supplied nitrogen on the Tamale and Nyankpala shale sites. The more striking additions and exceptions to the pattern occur at Damongo and the Nyankpala shale sites, where lime at the former and nitrogen at the latter were ineffective and where significant positive interactions +NL and +KL occurred at both. It would seem from this that the acidifying action of ammonium sulphate can sometimes outweigh the benefit of additional nitrogen and that liming was not effective here unless the soil pH or Ca/K ratio had been made too low by the addition of fertilizers. The interaction −NK on the Nyankpala shales conforms to the apparent pattern of +NK for cereals on southern potash-deficient sites (Wenchi and Kwadaso granite) and −NK on northern sites where potash is not required (see below).

Yams at Tamale responded to the organic treatments and also to lime in the presence of potassium; at both types of Nyankpala sites superphosphate and lime increased yields, and on the shale ammonium sulphate reduced yields, especially in combinations with potash. It seems probable, therefore, that the main requirements of this crop are plenty of organic matter and a good supply of divalent cations. The effect of mulch has been exaggerated on these trials as the local practice of 'capping' the yam mound with grass or leaves was sometimes omitted from the unmulched plots; 'capping' is known to improve germination and yields significantly. The groundnut responses are difficult to explain. Lime was everywhere effective and ammonium sulphate usually harmful; but the Nyankpala sites seem to have been exceptionally unresponsive to superphosphate and organic treatments, although yams and cereals on these sites benefited particularly from the same treatments. Since the groundnut yields were low, and rosette disease was severe in some seasons, it may be that unfavourable environmental conditions nullified responses to the treatments; on the other hand, small-scale trials at Nyankpala have shown large groundnut responses to sodium molybdate [7], so molybdenum deficiency may be inhibiting treatment responses. As would be expected, yields on sandstone sites were higher than on the shallow silty shale sites.

The stations Babile, Tono, Zuarungu, and Manga on granite soils in the far north form a group characterized by severe shortage of phosphorus. The most common pattern of cereal response is +N, +P, +M, +D, +NP, −PD, and −NK; the last named may indicate either that it is harmful to add potash to soils which have been acidified by ammonium sulphate, presumably because of antagonism between potassium and the reduced concentration of divalent cations, or that potash application hinders uptake of nitrogen by the maize [8]. Neither lime nor potash

have been beneficial over the eight years of cropping as a whole. Babile seems to have had exceptional interactions, −NL instead of the usual +NL, −NM instead of +NM, +PD instead of −PD, +KM instead of −KM, and a large −NPM. These are difficult to interpret, but seem to indicate the importance of nitrogen; for example, the nitrogen content of manure might account for +PD. Manga responded particularly well to ammonium sulphate and has the attendant significant interactions −ND and −NPD, which indicate that the kraal manure supplied nitrogen as well as phosphorus.

Groundnuts responded well to superphosphate and kraal manure at all the sites, mulch and lime were rather less effective, and ammonium sulphate and potash were harmful. The general response pattern is −N, +P, −K, +L, +M, +D, +NL, −PD; at Tono and Zuarungu where neither ammonium sulphate nor lime had such large effects as at the other two stations, the interaction LM was significant and negative. Babile was again exceptional and had large positive values for the interactions KM, KD, and LD, which imply that the bad effects of potash were effectively remedied by the organic treatments and that lime and kraal manure were especially effective in combination.

Development of Deficiencies with continued Cropping

In order to see how responses to treatments have changed with continued cropping, in Table 2 sites have been grouped into zones to give reasonably balanced comparisons between different periods of time. Main effects in the earlier years, when rates of fertilizer application were two or four times as great as in later years, have been adjusted by multiplying by 0·67, but values for interactions have not been so adjusted, and all interactions higher than first-order have been omitted. The treatment effects given are considered to be estimates of the effects of the standard rates in use after 1949.

The Forest Zone. Maize yields in Table 2 show the effects of severe rust attack in the third to fifth years. Nevertheless, the responses expressed as percentages of the mean yield probably reflect fertility trends reasonably accurately. In the first two years phosphorus was the limiting factor and potassium was needed only when the phosphorus requirement had been met. The small positive effect of mulch is wholly accounted for by the phosphorus it supplied. Later years show the progressive development of deficiency of phosphorus (increasing +P and decreasing −PM) and of potassium (increasing +K, +PK, and −KM), while after seven to eight years there is a sign of response to lime. Mulch in combination with superphosphate and muriate of potash (i.e. M+PM +KM) produced about half the response obtained in their absence, so that at least half the effect of mulching is probably due to provision of these nutrients.

Cassava responded increasingly to potassium after the second year from fallow. Responses to mulch were even greater, especially after four years' cropping, and although the value of −KM does not increase correspondingly, the main function of mulch may have continued to be the supply of potassium.

TABLE 2. *Mean Yields in lb./acre, and Treatment Main Effects and Significant Interactions Expressed as a Percentage of Mean Yield, at Different Periods During Continuous Cropping*

At sites where one trial had mulch and the other had kraal manure the number of trials with each of these treatments was approximately half that quoted.

The dash — indicates that no estimate of the effect is available. The signs * and † indicate significance at the $P = 0.05$ and $P = 0.01$ level respectively.

	Forest zone														*Ashanti Voltaian savannah*									*Savannah long-rest sites*								
Trial sites	*Aiyinasi and Kwadaso (6 trials)*								*Aiyinasi (2 trials)*				*Kwadaso (4 trials)*		*Wenchi and Ejura (5 trials)*				*Ejura (2 trials)*		*Wenchi and Ejura (3 trials)*			*Ejura and Damongo (4 trials)*			*Damongo (2 trials)*				
Crop	MAIZE				CASSAVA				GROUNDNUTS (*direct effects*)				GROUNDNUTS (*residual*)		CEREALS				YAMS		GROUNDNUTS (*residual*)			CEREALS			GROUNDNUT HAULMS				
Years after fallow	1–2	3–4	5–6	7–8	1–2	3–4	5–6	7–8	1–2	3–4	5–6	7–8	5–6	7–8	1	2	3	4–5	1–2	3–4	1	2	3–4	1–2	3–4	5–6	4	5	6	7	8
Mean yield (lb./acre)	1180	505	561	794	13469	15776	10999	10477	898	790	604	436	699	359	856	1198	800	938	9142	7207	910	857	743	1010	854	1561	6231	4719	6303	6186	6804
Treatment effects as % of mean:																															
N	1	−1	−7•	4	−1	0	−8	6	1	−8	1	−8	0	−2	36†	37†	14•	23†	8	−8	0	−4	−16†	24†	18†	16†	7	18†	5	10†	7
P	18†	33†	49†	48†	4	4	1	−6	7	2	16•	15•	12†	24†	11†	45†	32†	16•	−1	15•	10†	7•	7	7	20†	27†	21†	12†	18•	29†	24†
K	1	10•	12†	9•	1	12†	21•	29†	4	10•	−3	4	0	4	3	16•	14•	−7	0	2	−1	7•	−1	4	−6	−6	−5	−3	8	6	4
L	2	2	5	12†	1	1	9	4	3	9	10	14•	−3	−2	−1	−9	−1	6	−1	2	2	−2	4	0	5	1	9	17†	−1	14†	−1
M	7•	42†	40†	42†	3	14†	42†	57†	−7	3	7	21†	3	24†	−3	22†	13	0	6	27†	3	7•	7	−6	10•	21†	−6	9	21•	13†	9
D	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
NP																								0	3	12•	−8	−10•	−14	−10†	−18†
NK															7	10	22†	6	−3	14•	2	8•	5								
NL																			2	24†											
NM																															
ND	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PK	7•	14•	15†	13†																											
PL																															
PM	−9•	−4	−4	2	−4	−9•	5	0	−4	−14•	−1	−13•			−1	2	−14•	−3						1	−7	−9•	−6	8	−2	−10†	−2
PD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
KL																					−7•	1	0	−1	9•	9•					
KM	−3	−14•	−18†	−8•	−4	−16†	−11	−15†	−1	−18†	−5	−18†	0	−16•																	
KD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LM																															
LD	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
M in presence of NPKL	−4	21	11	34	−2	−18	23	44	−13	−29	0	−1	−3	17	−9	22	6	1	3	43	13	4	11	−17	−3	−3	−24	9	16	0	14
D in presence of NPKL	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 2 (*cont.*)

Trial sites	*Savannah long-rest sites (cont.)*				*Northern Voltaian short-rest sites*										*Northern granitic sites*									
	Damongo (2 trials)				*Tamale and Nyankpala (6 trials)*			*Tamale and Nyankpala (4 trials)*			*Tamale and Nyankpala (4 trials)*				*Zuarungu, Tono, Manga (6 trials) (a)*			*Babile (b) (2 trials)*		*Zuarungu, Tono, and Manga (6 trials) (a)*			*Babile (b) (2 trials)*	
Crop	GROUNDNUTS				CEREALS			YAMS			GROUNDNUTS				CEREALS			CEREALS		GROUNDNUTS			GROUNDNUTS	
Years after fallow	1–2	3–4	5–6	7–8	1–3	4–6	7–9	1–3	4–6	7–9	1–2	3–5	5–6	7–6	1–3	4–6	7–9	1–3	4–6	1–3	4–6	7–9	1–3	4–6
Mean yield (lb./acre)	969	774	713	656	1048	1129	1405	7791	4747	9893	795	536	581	453	695	786	632	979	935	631	667	815	780	711
Treatment effects as % of mean: N	8†	−1	3	−2	11†	15†	16†	−3	−12	5	−7*	−8	−13	−6	13†	16†	13†	6	29†	−3	−4	−7*	−10*	−23†
P	21†	11*	15†	26†	21†	24†	27†	3	14*	9†	−5	6	16*	11*	30†	29†	41†	32†	47†	17†	22†	21†	21†	39†
K	−2	−7	−4	4	−1	4	3	−5	−2	0	7*	−9	2	−2	−2	7†	1	0	3	−7*	−3	−3	−6	−13*
L	4	6	4	5	8*	14†	11†	5	7	13†	7*	21†	35†	16†	1	2	1	1	6	5*	2	9*	3	19†
M	12†	12*	27†	24†	9*	30†	35†	35†	39†	36†	—	20†	—	8	—	85†	50†	24†	48†	43†	14	27†	9*	8
D	—	—	—	—	26*	55†	57†	5	21†	28†	10*	−7	30†	35†	19†	44†	68†	1	6	—	17†	32†		
NP	−19†	−2	4	9	4	8*	14†								19†	9†	19†	0	11*				−10*	−5
NK								1	−3	−6*								−3	−10*					
NL											−4	11*	8	8				−10*	−4	3	10*	4		
NM	4	−19†	−13*	1														−8*	−3					
ND	—	—	—	—																				
PK											−11*	−10	−5	6										
PL	−2	−12*	−3	−18*	−2	−9*	−6								−5*	3	−2			−2	−3	−8*		
PM	4	1	−1	−15*	−9	−9	−14*								—	−11	−16†			−20†	−7	−13	−8*	−12*
PD	—	—	—	—				2	4	6*					−7*	−22†	−8*			—	−10	−12†		
KL																								
KM								−11*	7	−3								9*	7				5	18†
KD	—	—	—	—																−1	−16	−18*	3	12*
LM	—	—	—	—	2	−9	−14*																	
LD																								
M in presence of NPKL	17	−4	7	0	4	18	22	35	25	41	—	—	—	—	—	83	36	32	62	18	0	−3	7	22*
D in presence of NPKL	—	—	—	—	6	27	20	−2	25	20	14	0	32	45	13	14	54			—	14	24		

(*a*) Figures for mulch effects in both these columns (i.e. cereals and groundnuts at northern granitic sites) are based on one trial only, instead of the quoted six trials, owing to wrong applications of manure.

(*b*) At Babile responses to mulch and kraal manure have been combined to give mean response to the organic treatments.

Yields of groundnuts have fallen steeply and steadily at both Aiyinasi and Kwadaso. Responses to superphosphate and to lime at Aiyinasi have increased, but not sufficiently to counterbalance falling yields on the plots receiving both treatments. Mulch was effective only after seven years and at Aiyinasi it was primarily a supplier of available phosphorus, while its residual effects at Kwadaso were also probably chemical rather than physical. Although there was no consistent response to potassium it is noteworthy that at both stations the interaction KM was significant and negative, for in these experiments it has often been found that the first sign of an incipient phosphorus or potassium deficiency is a significant negative interaction with the organic treatment rather than a significant main effect.

None of the crops tested in the Forest Zone showed any indication of a worth-while response to ammonium sulphate.

The Ashanti Voltaian Savannah. This is not a very satisfactory grouping as it includes Wenchi which is exceptionally short of potassium and Ejura which is not. Cereals showed no clear trends in either mean yield or responses, but it seems that, in accord with previously reported results [1], in the first year or two after grass fallow nitrogen was particularly short and phosphorus reasonably abundant, while later the relative positions were reversed. Continued application of ammonium sulphate seems to have caused potassium deficiency.

The figures quoted for yams are rather slender evidence that this crop did best immediately after the fallow and may suffer from lack of available phosphorus in the third and fourth years. Unlike the experiments conducted on farmers' land [4] these trials show little advantage from applications of ammonium sulphate to yams.

Groundnut mean yields apparently declined and residual effects of ammonium sulphate and superphosphate became progressively less with cropping. This apparent action of superphosphate is unexpected and the figures are probably based on too few years and trials for valid conclusions to be drawn.

Savannah long-rest sites. These sites had probably more than ten years' rest under natural savannah vegetation before the trials were started. Although mean yields of cereals seem to have been well maintained, responses to fertilizers showed quite regular trends. Nitrogen was most needed immediately after the resting period, whereas phosphorus became increasingly deficient with cropping. The rise in response to superphosphate was accompanied by rising responses to mulch and the interactions NP and −PM. The interaction between potassium and lime became significant in the later years, suggesting that the balance of cations was becoming critical.

In the first two years after fallow, groundnuts had the response pattern +N, +P, −NP, which indicates response to the sulphur in the superphosphate and ammonium sulphate [1, 5]; in later years this sulphur shortage disappeared, thus behaving similarly to the nitrogen deficiency described above. Mean yields decreased with continued cropping, while soil phosphorus supplies also fell, as shown by the rising values for +P, +M, and −PM. The negative interaction between

superphosphate and lime may mean that the calcium content of the superphosphate was becoming important at Damongo or perhaps more plausibly that the lime modified the availability of soil phosphorus. Haulm weights were recorded during the last five years and show that although ammonium sulphate then had no effect on kernel yields it improved foliage growth significantly in the absence of superphosphate. This suggests that sulphur may still be in short supply although sufficient for kernel formation. The haulm weight figures show no convincing trends with time.

Northern Voltaian savannah short-rest sites. Here, where sites had been rested for less (often for much less) than ten years, cereals responded increasingly to all fertilizer treatments and gave no sign of any extreme nitrogen shortage in the first year. Liming was effective, but in later years the regular applications of kraal manure seem to have made it unnecessary. The very beneficial effects of the organic treatments, especially kraal manure, have caused mean yields to increase slightly with cropping.

Yams responded increasingly to superphosphate, to lime, and to kraal manure. The very large effects of mulch were partly due to the omission of 'capping' from unmulched plots in some years, as mentioned previously.

Groundnut mean yields fell off with continued cropping, and superphosphate effects grew more important. Lime was outstandingly effective after the first two years, during which potash was slightly beneficial. Kraal manure was more effective in the presence of inorganic fertilizers than in their absence.

Northern Granitic sites. All these had been more or less continuously cropped for many years before the trials started, dung and refuse or kraal manure being applied about every third year. The soils had therefore probably reached a relatively stable, and low, level of fertility before the trials started. All crops showed large and increasing responses to superphosphate and kraal manure, while the negative interaction between these two treatments shows that a considerable proportion of the effect of the manure was due to its phosphorus content. Part of the effect of mulch can be explained similarly. However, these organic treatments retained most of their effectiveness even in the presence of the inorganic fertilizers; this suggests the effects of their organic matter content on the physical properties of the soil may be very important, especially in later years. The organic matter would decompose comparatively slowly during the growing season, to provide pockets of available and balanced nutrients, which would be repeatedly replenished. The mulch would also improve rain acceptance, prevent capping and delay drying out of the top soil.

The negative effects of ammonium sulphate and potash on groundnuts and their growing response to lime, coupled with the increasingly negative PL interaction, indicate that calcium was becoming deficient. It seems that on continuously cropping these soils with cereals and groundnuts, it is once again calcium rather than potassium which is needed first.

Soil studies on the experimental sites will be reported, and discussed, in relation to the results here reported, in Part II.

REFERENCES

1. P. H. NYE, *Empire J. Expt. Agric.*, 1951, **19**, 217 and 275; 1952, **20**, 47.
2. C. J. TAYLOR, *The Vegetation Zones of the Gold Coast*, Bull. No. 4, Forestry Department, Accra, Govt. Printer, 1952.
3. ANON., *Geological Map of the Gold Coast*, Survey Department, Accra, Govt. Printer, 1955.
4. D. STEPHENS, *Empire J. Expt. Agric.*, 1960, **28**, 1.
5. —— ibid., p. 151.
6. P. M. AHN, *The Soils of Aiyinasi Agricultural Station and their Relationship to the Soils of Nzima, Western Region*, Agricultural Department, Technical Report No. 26, Accra, Govt. Printer, 1957.
7. D. STEPHENS, *Empire J. Expt. Agric.*, 1959, **27**, 324.
8. L. B. NELSON, *Advances in Agronomy*, 1956, **8**, 331.

(*Received 10 August 1959; as revised 19 July 1960*)

ANIMAL PRODUCTION

JOURNAL OF THE BRITISH SOCIETY OF ANIMAL PRODUCTION

Contents of Volume 3, Part 1, February 1961

MAHADEVAN, P., and MARPLES, H. J. S. An analysis of the Entebbe herd of Nganda cattle in Uganda.

FRASER, J. D. A comparison of whole milk with buttermilk in the rearing of calves for veal. 1. Rearing and growth.

BARTON, R. A., and KIRTON, A. H. A comparison of whole milk with buttermilk in the rearing of calves for veal. 2. Slaughter and carcass composition data.

SHORTHOSE, W. R., and LAMMING, G. E. The effect of testosterone and oestradiol on growth rate and carcass quality of fattening hoggets.

PRESTON, T. R., CHARLESON, E. B., MACLEOD, N. A., ROSEN, G. D., and VERNON, J. The effect of Hydroxyzine on growth, endocrine, and carcass characteristics of lambs.

BLAXTER, K. L., WAINMAN, F. W., and WILSON, R. S. The regulation of food intake by sheep.

OWEN, J. B., and INGLETON, J. W. A method of collecting faeces from ewes.

HALE, R. W. Heritabilities and genetic correlations of egg production and other characters in a White Wyandotte flock.

WATSON, J. H. The influence of contemporaneity, genetic variation and herd differences on milk yield and fat percentage.

LODGE, G. A., and McPHERSON, R. M. Level of feeding during early life and the subsequent reproductive performance of sows.

BELLIS, D. B. Supplementation of bacon pig rations by aureomycin and copper sulphate.

THIS *Journal* is a continuation and expansion of the *Proceedings of the British Society of Animal Production* (*1944–58*), and appears three times a year in February, June, and October. The annual subscription is 45*s*. ($7.50 in U.S.A. and CANADA), single parts 17*s*. 6*d*. ($2.75 in U.S.A. and CANADA) net. Orders and subscriptions should be sent to:—

OLIVER AND BOYD, LTD.

Tweeddale Court, 14 High Street, Edinburgh, 1

THE JOURNAL OF AGRICULTURAL SCIENCE

VOL. 56 PART 1 FEBRUARY 1961

Contents

ASKER, A. A. and BADER, L. H. Environmental factors affecting persistency of lactation in Egyptian buffaloes.

ASKER, A. A. and BADER, L. H. Repeatability and heritability of persistency of lactation and initial milk yield in the Egyptian buffaloes.

SMITH, C. A. Studies on the Northern Rhodesia Hyparrhenia veld. Part II. Seasonal milk production using natural veld.

REITH, J. W. S., INKSON, R. H. E., STEWART, A. B., HOLMES, W., MACLUSKY, D. S., REID, D., HEDDLE, R. G., CLOUSTON, D. and COPEMAN, G. J. F. The effects of fertilizers on herbage production. Part I. The effects of nitrogen, phosphate and potash on yield.

SUMPTION, LAVON J. Multiple sire mating in swine; evidence of natural selection for mating efficiency.

WIDDOWSON, F. V., PENNY, A. and WILLIAMS, R. J. B. Applying nitrogen fertilizers for spring barley.

ROBINSON, J. B. D. Nitrogen studies in a coffee-soil. II. The influence of mulch on natural and fertilizer levels of nitrate and ammonia in the top-soil. III. The comparative efficiency of ammonium sulphate and urea fertilizers in the presence and absence of an organic mulch measured in terms of crop yield.

LEWIS, D. The absorption of subcutaneously implanted thyroxine in the sheep.

ALLEN, D. M. and LAMMING, G. E. Nutrition and reproduction in the ewe.

BLAXTER, K. L. and WAINMAN, F. W. Environmental temperature and the energy metabolism and heat emission of steers.

BREDON, R. M., MARSHALL, B. and JUKO, C. D. The nutrition of Zebu cattle. Part I. Equipment for the separate collection of urine and faeces from steers. Part II. The techniques of digestibility trials with special reference to sampling, preservation and drying of faeces. Part III. Digestibility techniques: investigation of the effects of combination of dry faeces, length of digestibility trials and number of animals required.

SMITH, R. H. The development and function of the rumen in milk-fed calves. II. Effect of wood shavings in the diet.

GLOVER, J. Comparative efficiency of digestion of feeds by ruminants and pigs.

GLOVER, J. and DOUGALL, H. W. Estimation of the average total digestible nutrients in pig feeds.

HANLEY, F., JARVIS, R. H. and WHITEAR, J. D. The effects of time of ploughing and time of drilling on the development and yield of the winter wheat crop following a clover ley.

ADAMS, S. N. The effect of time of application of phosphate and potash on sugar beet.

BATH, I. H. and HEAD, M. J. The *in vitro* production by rumen micro-organisms of volatile fatty acids from cellulose and hemicellulose labelled with ^{14}C.

HARKER, K. W., ROLLINSON, D. H. L., TAYLOR, J. I., GOURLAY, R. N. and NUNN, W. R. Studies on the habits of Zebu cattle. VI. The results on different pastures.

Articles are illustrated with plates and figures

Subscription price, 60*s.* net per volume of three parts; single parts, 25*s.* net. Two volumes are issued each year. Orders may be sent to any bookseller or to the

CAMBRIDGE UNIVERSITY PRESS

BENTLEY HOUSE, 200 EUSTON ROAD, LONDON, N.W. 1